AD-A107 270 NAVAL RESEARCH LAB WASHINGTON DC F/G 4/1

FIELD EXPERIMENTS WITH ARTIFICIAL AEROSOLS AT SAN NICOLAS ISLAN--ETC(U)

OCT 81 S G GATHMAN, B G JULIAN, L A MATHEWS

UNCLASSIFIED NRL-MR-4638 NL

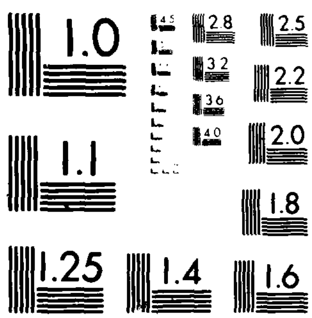
1 OF 1

END

DATE FILMED

12-81

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

AD A107270

14 NRL-MR-4648

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: NRL Memorandum Report 4648	2. GOVT ACCESSION NO.: AD-A107270	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): FIELD EXPERIMENTS WITH ARTIFICIAL AEROSOLS AT SAN NICOLAS ISLAND, CALIFORNIA		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): S.G. Gathman, B.G. Julian,* L.A. Mathews,** and R.M. McClung**		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Research Laboratory, Washington, DC 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61153N; WR 01137; ~~43-1114-0-1~~
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Air Systems Command, Washington, DC 20361		12. REPORT DATE: 28 October 1981
		13. NUMBER OF PAGES: 43
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

16 NR0 11 37

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Present Address: *JAYCOR, Inc., 205 South Whiting St., Alexandria, VA 22341
**Naval Weapons Center, China Lake, CA 93555

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Salty Dog	Diffusion	Aerosol
Hygroscopic nuclei	Helicopter	Extinction
Scattering coefficient	Fog	
Relative humidity	Visibility	
Plume	Infrared	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Artificial fogs grown on hygroscopic (Salty Dog) nuclei were produced in the marine environment over Laser Bay, San Nicolas Island, California. These fogs were studied using over water optical extinction measurements in the visual, near and far infrared bands as well as by aerosol size measurements from an instrumented aircraft and from a shore based instrument. These studies show that optical extinction in the visible and near infra red wavelengths produced by biologically safe hygroscopic nuclei can be generated in military significant scales in the marine boundary layer.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251950

CONTENTS

Field Experiments with Artificial Aerosols at San Nicolas Island, California

INTRODUCTION

The marine environment offers unique advantages in the area of optical screening. The goal of this program is to use the vast amount of water stored in the marine atmosphere and transform it into condensed water droplets which block radiation of various wavelengths. The production of artificial aerosols upon which water fogs form is a key feature of this effort. One aspect of this effort, covered by this paper, concerns field tests of artificially produced fogs.

Field experiments in 1968 by the Naval Weapons Center showed that hygroscopic alkali chloride smokes, such as the Salty Dog pyrotechnic, were capable of forming fog and stratus in a marine environment (Blomerth et al, 1970). Limited field tests (Hindman and Finnegan, 1977 and Hindman et al 1979) showed that these artificial fogs provided screening agent capabilities. Further limited tests by NRL in 1978 and 1979 of the pyrotechnics, Salty Dog and NWC29, further demonstrated their usefulness as screening agents in a marine atmosphere (Gathman et al, 1979 and Gathman et al, 1981). The NRL work demonstrated it was possible in a high humidity environment to grow a droplet on a pyrotechnically generated, hygroscopic nucleus and then stabilize the droplet to prevent evaporation in a drier environment. Thus, larger drops were produced by this method than those obtained from combustion in the drier ambient air. This report covers an actual test of the "Salty Dog" pyrotechnic for production of mesoscale artificial fogs in a marine environment. This test was performed in cooperation with an EOMET experiment on San Nicolas Island, California during a "highmode" experiment. Thus the amount of instrumentation available was expanded for the measurement of the artificial plumes produced by this method.

BACKGROUND

San Nicolas Island, (SNI) a Navy operated facility, is located approximately 102 km south-southwest of Point Mugu, California. It has an area of approximately 50 square kilometers with a length of 14.5 km and a width of 5 km. The nearest landfall is tiny Santa Barbara Island located 46 km to the northeast. Los Angeles is 120 km to the northeast. The site is remote and the probability of continental influence on the weather at the site is not great. Its location with respect to the continent is shown in Fig. 1.

One of the unique features of this facility is the existence of a double ended overwater transmission path. The transmission measurements are made with a Barnes Engineering Company 14-712 VRL Atmospheric Transmissometer consisting of three radiometer heads, and visible and blackbody sources to cover the visible, near, mid and far infrared wavelengths. The altitude of the beam path above the water level is approximately 15 meters.

Figure 2 shows the island and the location of the important sites on this island. The radiometer heads are located at "A" near the NRL site "N" and the two paths have lengths of 4.07 km and 2.51 km. The radiometer instrumentation is operated in cooperation with the Optical Signatures Program, Naval Weapons Center and the Electro-Optical Meteorology Program (EOMET), Naval Ocean Systems Center (NOSC).

Manuscript submitted August 20, 1981.

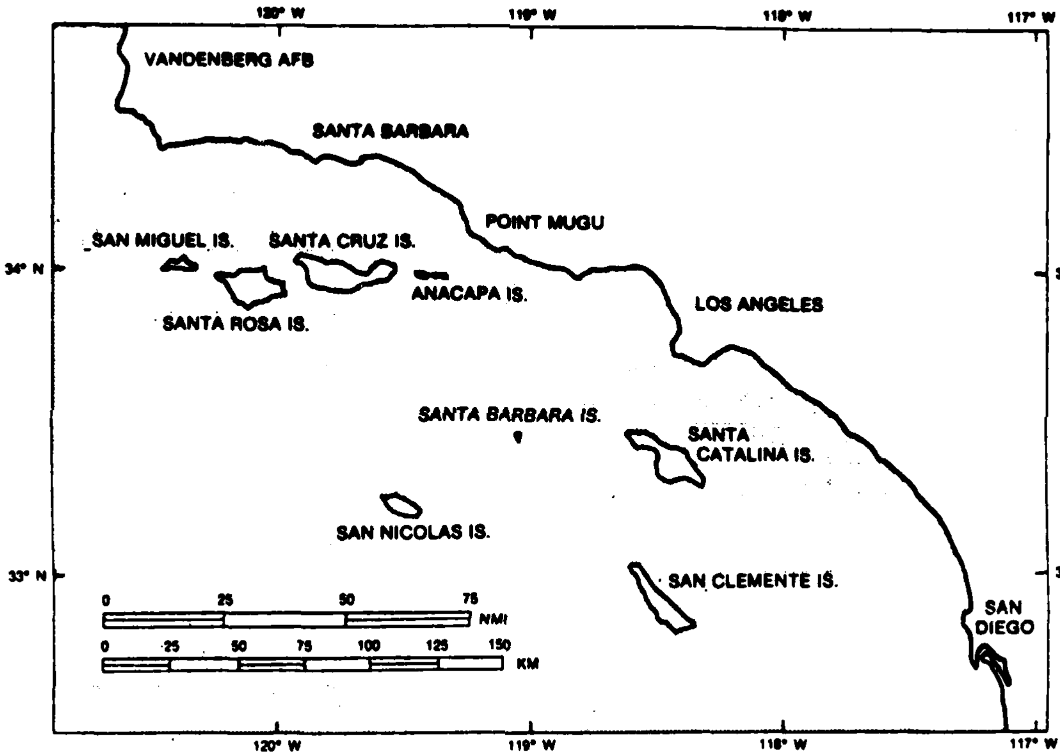


Fig. 1 — Location of San Nicolas Island, Calif. with respect to west coast cities

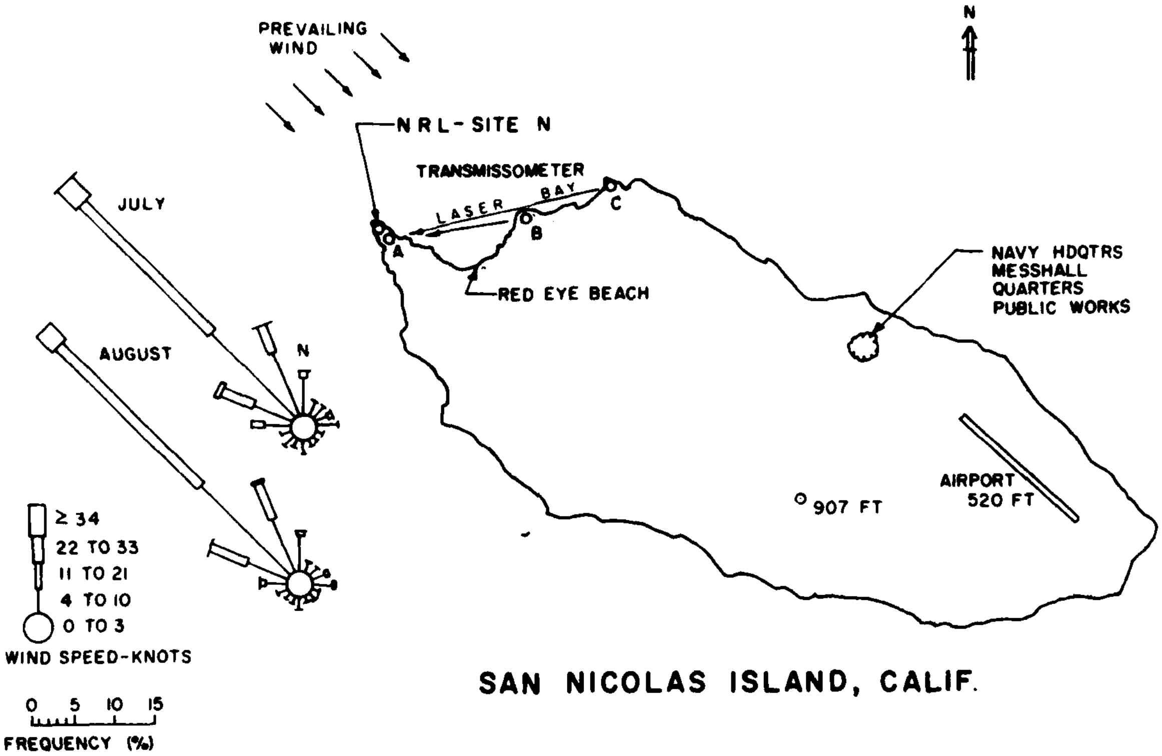


Fig. 2 — San Nicolas Island, its sites important to this report and climatic wind roses for the months of July and August

At the NRL site a Particle Measuring Systems (PMS) particle size spectrometer was in operation. This instrument is capable of obtaining data on atmospheric particles, having diameters that range from 0.7 to 45 micrometers. These data were being recorded every two minutes at the NRL site so that it was capable of distinguishing between normal background aerosol and the artificial aerosol produced by our tests.

An additional feature of the SNI site during the EOMET highmode of operation is the availability of both standard meteorological measurements made at several stations about the island and an especially equipped micrometeorology site also located at the NRL tower. Instrumentation from this site is believed capable of looking at both momentum, heat and moisture flux across the air-sea interface measured by both the bulk aerodynamic method and the profile method (T. V. Blanc, 1980). Many other micrometeorological parameters are available which might be of interest in depicting the actual conditions upwind in which the artificially produced aerosol are embedded.

An atmospheric radon gas monitoring station was also in operation to detect if the air mass was truly marine or had some continental aspects. (Larson,1981).

The island maintains an airfield which is useful in coordinating the experiment and as a base of operations for aircraft involved in the experiment. In general the timing of the artificial fog generation experiment to coincide (on a not to interfere basis) with the EOMET highmode experiment benefited all concerned. The EOMET personnel were interested in their ability to detect an unusual aerosol event with their instrumentation. Their measurements proved invaluable in the interpretation of the artificial aerosol experiment.

Of particular value were the aerosol measurements made by D.R. Jensen with the NOSC aircraft. Measurements made with airborne instrumentation are computer processed and averaged to produce the calculated aerosol extinction coefficient (b) for the wavelengths of .53, 1.06, 3.75 and 10.59 microns. The dN/dr values and the total aerosol volumes for both the atmospheric background and for the penetrations of the growing artificial plume were also obtained from the aircraft.

The climatology of SNI also showed the island to be an ideal location in which to carry out this experiment. Figure 2 shows from a 21 year average wind rose, that for the month of July a 60% chance of the wind coming from the northwest could be expected. This is an important consideration when a limited number of days are available in which to carry out the experiment.

PLUME STUDIES

The process of planning the experiment so that an artificially produced plume will go exactly where desired is a difficult task. All of the NRL Nantucket experiments (Gathman et al, 1979, 1981) consisted of a fixed source and a mobile sensor which could be maneuvered easily by a trained pilot for optimum results. This case is different because the plume's course is predetermined and the site of the transmissometer and the tower spectrometer placed at fixed locations on the island. Thus the success of the experiment depends on the ability of the planners to anticipate the path the aerosol plume will follow.

In preparation for this problem, consultations were undertaken with both the Calspan Corporation and the Naval Postgraduate School. The main question asked was how to best produce a plume that would pass through the transmissometer path and over the particle spectrometer site.

Some of the variables which had to be considered were the amount of pyrotechnic material needed and the burn time required, the altitude and relative position of the source with respect to the instrumentation, and the possibility of a mobile rather than a fixed source. The safety and controllability of the pyrotechnic aerosol generator was to be determined by these variables.

J. T. Henley and E. J. Mack of Calspan Corporation made some preliminary calculations with the Calspan Atmospheric Dispersion Model based on the Calspan laboratory tests of the "Salty Dog" material (Hanley and Mack, 1980). The input parameters for this model were:

Relative humidity	85%
Wind speed	7 m/s
Inversion height	500 m
Neutral stability	
Effective emission height	10 m
Sampling height	15.2 m
Background visibility	32 km

The results of this calculation for two burn rates of 126 g/sec and 13 g/sec are shown in Fig. 3. The lines shown are contour lines showing the areas where the 30 km, 20 km, and 10 km visibilities are predicted to be encountered.

It is obvious from this computer experiment that a higher burn rate is important to produce a wide plume which is easily detected as it crosses the transmissometer path. Variations in the burn rate and the effective emission height for a desired visibility of 12.8 km over a 4 km crosswind path as computed from Calspan's model are shown in Fig. 4.

This chart shows that if the source height is less than or equal to the transmissometer path altitude then the results would be independent of source height when the source-detection path length is 500 meters or over. However, the problems with an elevated source are shown by the 50 meter curve where its performance does not equal that of the lower height sources until the source-detection path is approximately 10 km.

The Calspan plots of the effects with variations in wind speed, stability and relative humidity are shown in Figs. 5, 6, and 7 where the 15.2 meter emission height is assumed. Their numerical experiment showed that results are invariant for inversion heights of 300, 500 or 700 meters. However, the model does show significant deviations depending on wind speed, stability and relative humidity.

Drs. K. Davidson and J. Hojstrup of the NPS used the Danish PUFF model (Mikkelsen,1979) to investigate the requirements of getting a reasonable uniform distribution of the concentration of a tracer along a 2.5 km crosswind path. They found that for a single fixed continuous source with a visibility of 1000 meters would require a distance from the release point to the target of 6 to 80 km dependent on the stability. (6 km for extremely unstable conditions, 80km for extremely stable conditions). These results were obtained from the Pasquill-Gifford curves for plume spread. Neglecting the stable and unstable end points, the necessary upstream distance to the source must still lie in the range of 8 to 45 km. Thus for a release point that far upstream the probability of not having the plume hit the target area because of small changes in wind direction is extremely large.

Instead another strategy was suggested by the consultants and adopted. Using the PUFF-model it was possible to estimate concentrations for short time releases even under non-stationary conditions. Thus it was possible to predict the downwind concentrations for a source moving upstream of the target. By moving the source, the tracer can be spread out over a large cross section and be positioned closer to the target. In order that material from all points along the path traveled by the source arrives at the target at the same time, the source must travel at an angle different from 90 degrees to the wind direction (assuming wind direction perpendicular to the target path). The optimum angle depends on the ratio of wind speed to source speed. In the model calculations it was assumed that the angle between wind direction and source path was 45 degrees, and it was further assumed that the source is capable of traveling 1270 m in 240 seconds (ground speed = 5.3 m/s). The calculations were done for

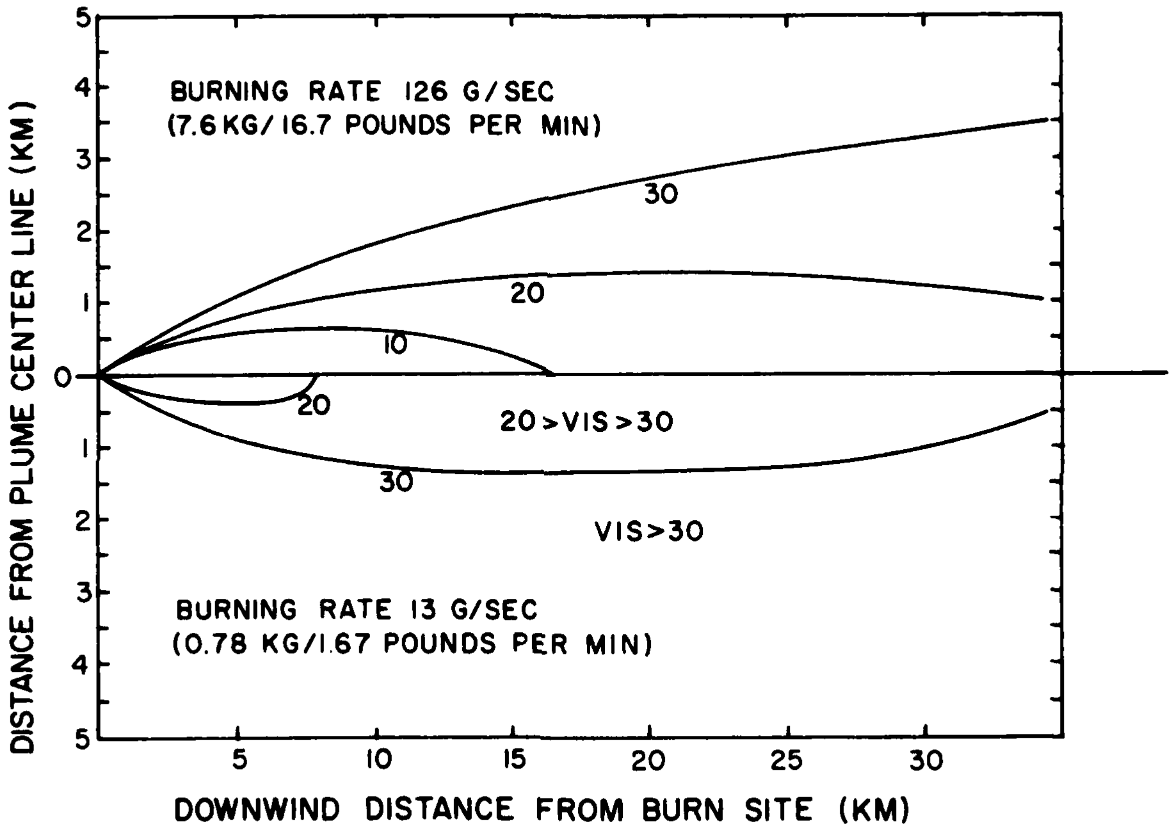


Fig. 3 — Plot of the plume from a point source of "Salty Dog" material as predicted from Calspan's dispersion model (Hanley & Mack, 1980)

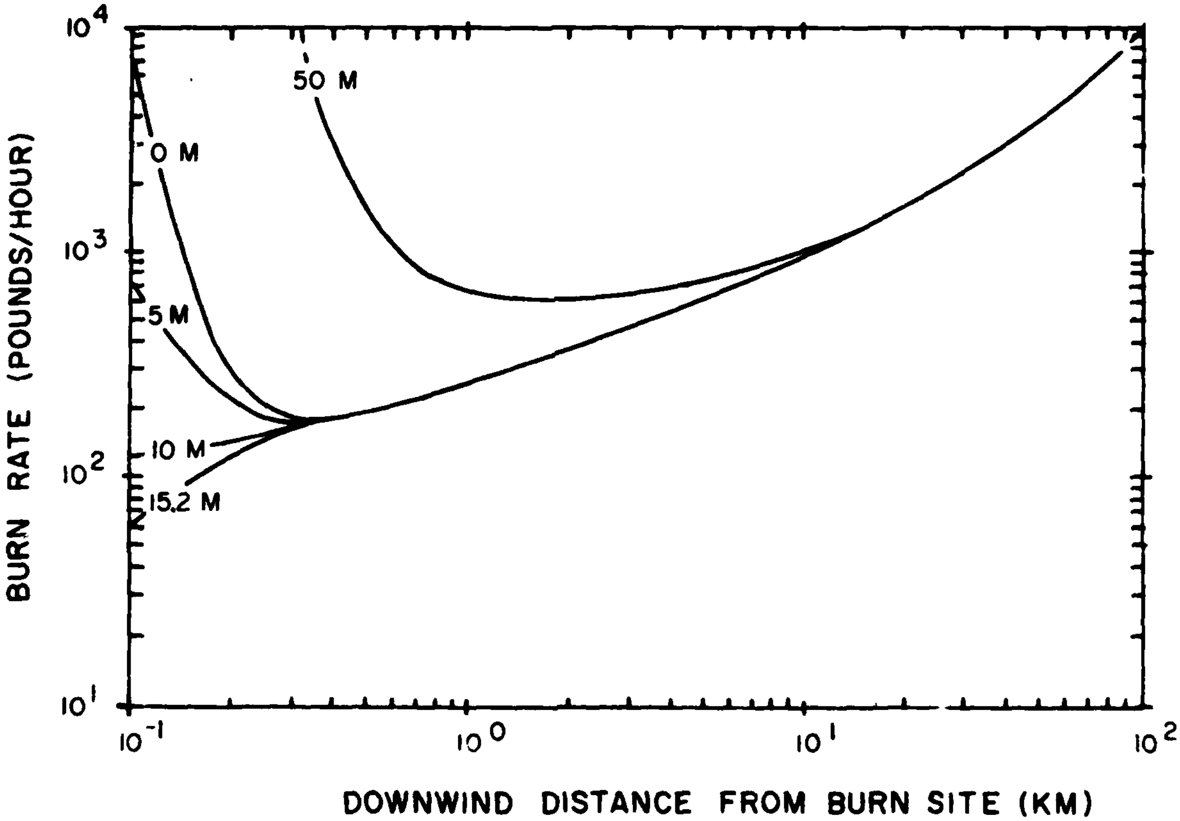


Fig. 4 — The effect of variations in the effective emission height and the required burning rate necessary to achieve a reduction in the visibility along the 4 km cross wind transmissometer path from 32 km to 12.8 km plotted as a function of the downwind distance from the source to the transmissometer. This calculation assumes a relative humidity of 85%, a wind speed of 7 m/s, an inversion base at 500 m, neutral stability and a sampling height of 15.2 m (Hanley & Mack, 1980).

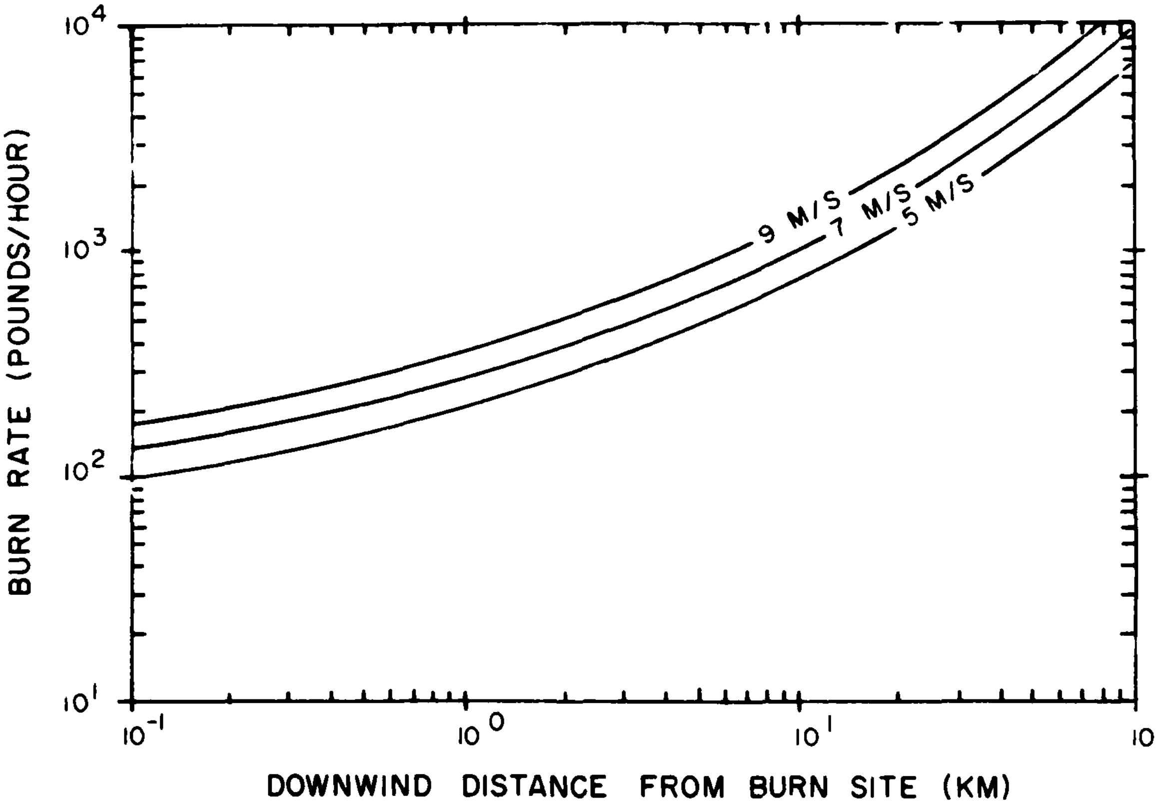


Fig. 5 — The effect of the variation in wind speed and the required burning rates of "Salty Dog" material necessary to reduce the visibility of the 4 km crosswind path from 32 km to 12.8 km plotted as a function of the downwind distance from the source to the transmissometer path. The calculation assumes a relative humidity of 85%, an inversion height of 500 m, neutral stability, an effective emission height of 10 m, and a transmissometer beam height of 15.2 m (Hanley & Mack, 1980).

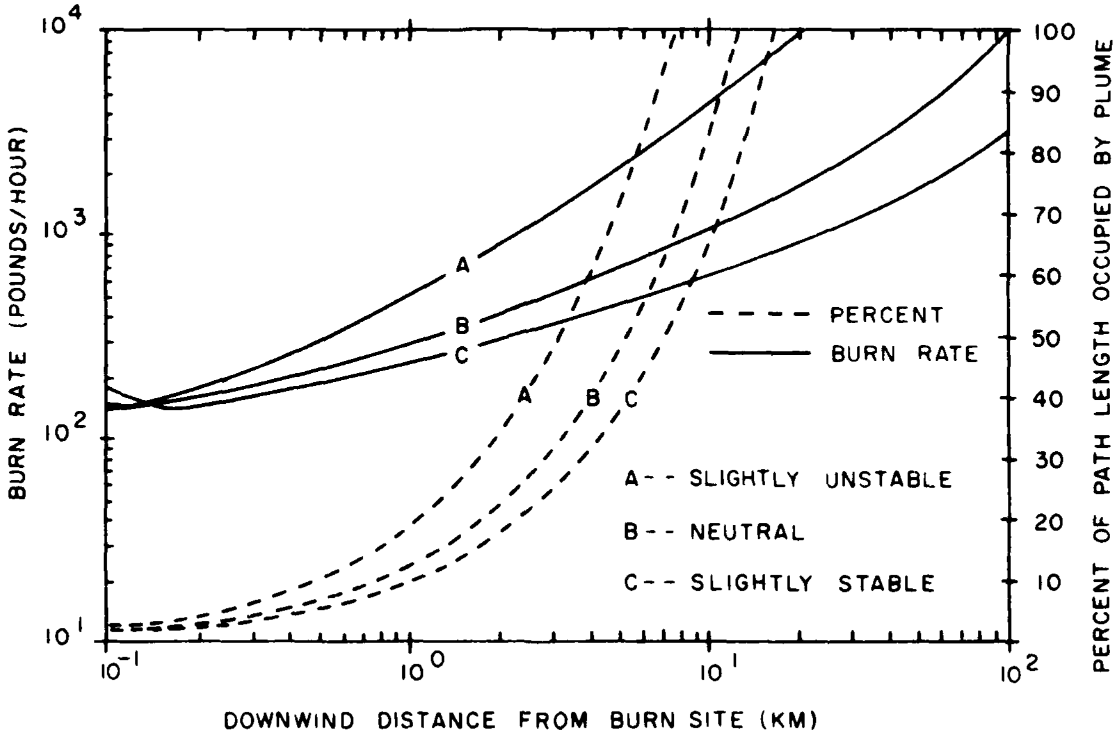


Fig. 6 — The effect of variations in stability on the required burning rate of "Salty Dog" material necessary to achieve a reduction in visibility from 32 km to 12.8 km across the 4 km crosswind transmissometer path plotted as a function of downwind distance from the source to the sensor path. The calculation assumes a relative humidity of 85%, a wind speed of 7 m/s, an inversion base height of 500 meters, an effective emission height of 10 m and a sampling height of 15.2 m (Hanley & Mack, 1980). Also shown in this figure is the percentage of the transmissometer path occupied by the plume under the three stability regimes and plotted as a function of downwind distance from the source to the sensor.

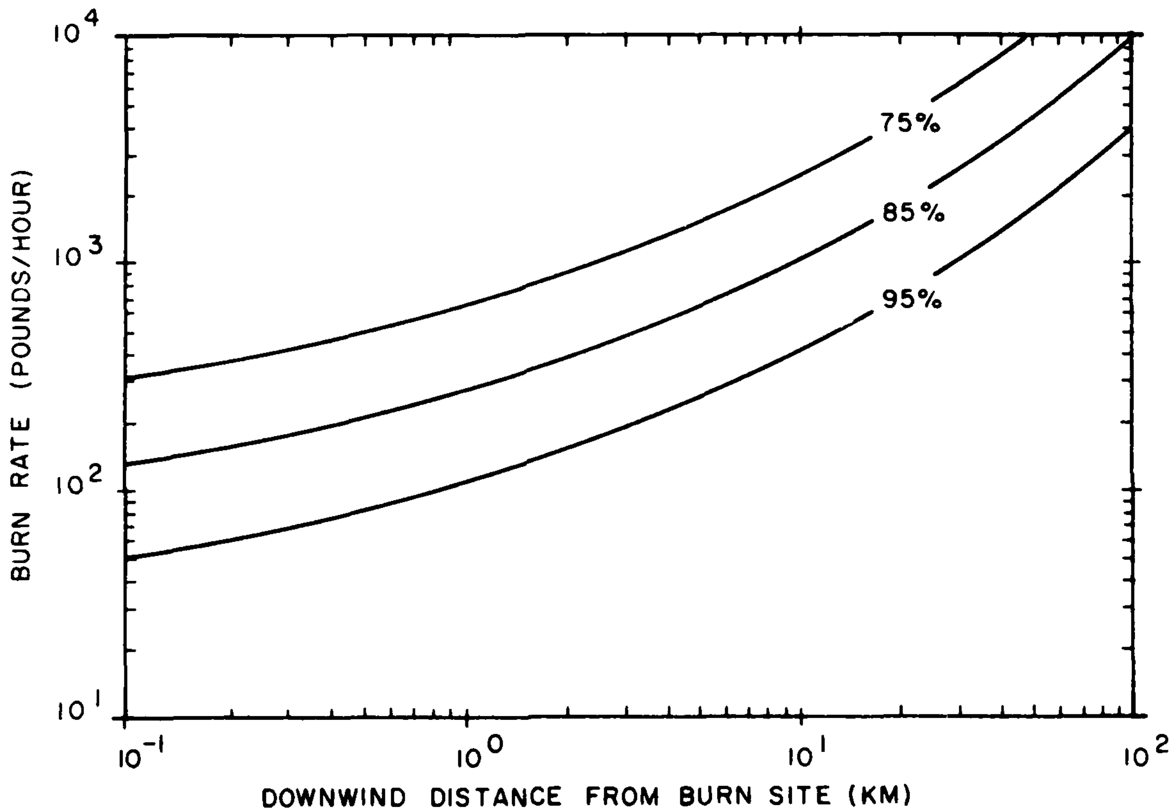


Fig. 7 — The effect of variations in the ambient relative humidity and its effect in the growth of the "Salty Dog" aerosol and the required burning rate necessary to achieve a reduction in the visibility from 32 km to 12.8 km in the crosswind transmissometer path plotted as a function of distance from the source to the sensor. The calculation assumes a wind speed of 7 m/s, a 500 meter inversion base height, neutral stability, an effective emission height of 10 m and a sampling height of 15.2 m.

3 constant wind speeds, 5,7.5, and 12.5 m/sec and for three different turbulent intensities represented by Richardson's numbers of 0.05, 0.1, and 0.2 (stable, neutral and unstable). They also assumed no reflection at surface, no capping inversion and a cold source (not buoyant).

The "Salty Dog" tracer to be used in the field experiments requires a time of at least 4 minutes to reach an equilibrium state, so for simplicity it is assumed that the target is at least a distance of 240 * 12.5 = 3000 meters from that part of the source path that is closest to the target.

The PUFF model was designed for distances up to 1 km, so the chosen distance is at the limit of the current models range. Extension to larger distances would require changes in the program, at least for buoyant sources since the plume rise formulation is valid only close to the source.

The grid used is 10 x 17 x 10 with resolution in the x and y directions of 300 meters, and a z resolution of 5 meters, so the volume represented is a box 3km wide, 5.1 km long and 50 m deep. The top view of this layout is shown in Fig. 8.

Concentrations comprise the individual source strengths which are assumed to be 1 g/sec. Figure 8 also shows the location of the sources and their times of emission so as to simulate a moving source.

It is essential that the source be capable of traveling a distance comparable to the target size during the release time. The reason is that the movement of the source is responsible for the main part of the spreading of the tracer.

At a wind speed of 5 m/sec, the cloud "front" comes in almost parallel to the target and fills up a good part of the target area along the y axis even for the stable case. For higher wind speeds the angle between the "front" of the aerosol plume and the y axis increases so that only a smaller part of the target is exposed. This of course can be remedied in the real situation by having the source travel at a higher speed and at a different angle with respect to the wind.

In Figs. 9, 10 and 11 the wind is blowing the plumes from the four sources parallel with the x axis toward the target line which is along the y axis. The concentrations which are expected at various points along the y axis are plotted in Figs. 9,10 and 11. These figures show the PUFF model's predicted results for three wind speeds and three stability regimes for the physical layout described above.

DELIVERY VEHICLE

These studies showed that it is possible to produce a relatively uniform cloud from a moving source. A source moving fast enough for an optimal angle of the source path to the wind speed would be necessary. It would be preferable to have the burntime adjustable to allow a less stringent requirement experiment of placing a broad bank of fog along an arbitrary line from a moving source so that the fog band, moving with the wind, would be parallel with the transmission path when it reaches this line.

From these studies we concluded that there were two possible vehicles which were available to provide the needed mobility and safety to transport the mobile pyrotechnic source. They were a shipboard platform or a helicopter. The problem of finding communications, adequate funds, and a lack of a deep water pier at SNI precluded the use of a shipboard delivery platform.

It was thus decided that a helicopter was to be used. A large selection of courses, speeds and altitudes could be obtained for the source. An additional advantage was that after the fog was emitted, the helicopter could then be used as an elevated photography platform.

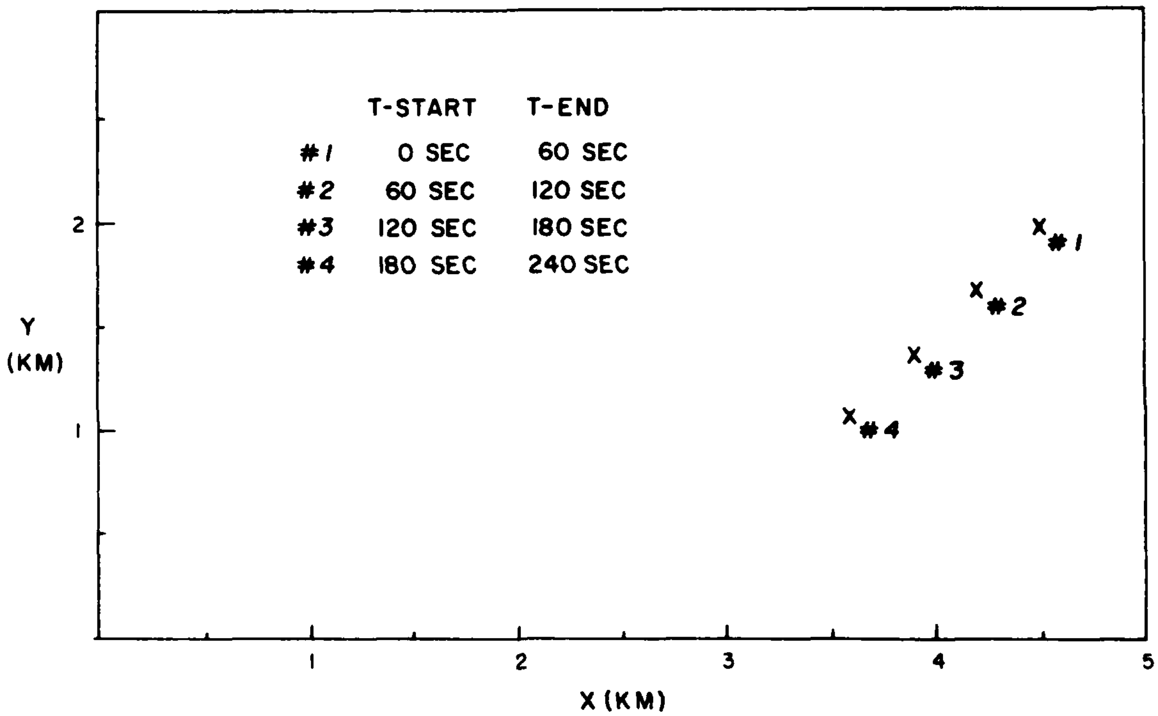


Fig. 8 — The layout of the grid network used to simulate a moving source from the PUFF model. Also shown are the starting and stopping times of the sources located at points number 1, 2, 3 and 4.

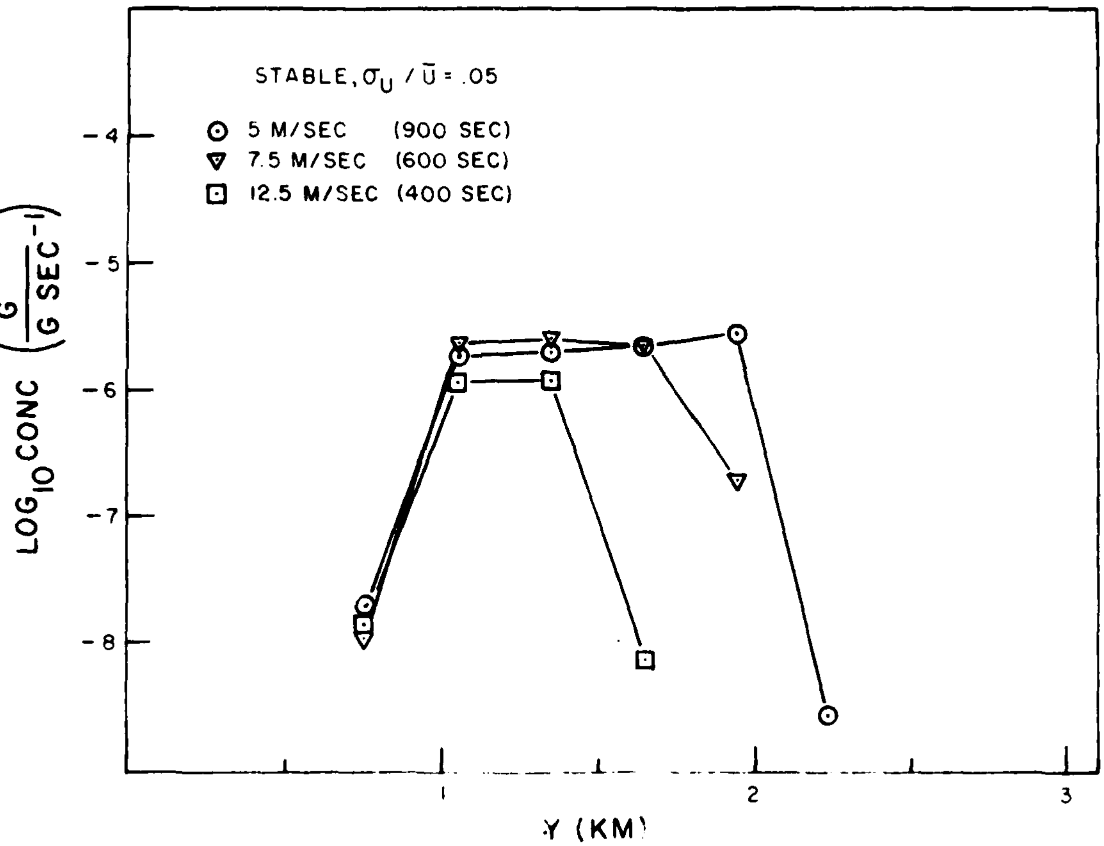


Fig. 9 — Concentration of a plume as it arrives at sensors located along the y axis as a function of the y distance from the four sources during a stable regime

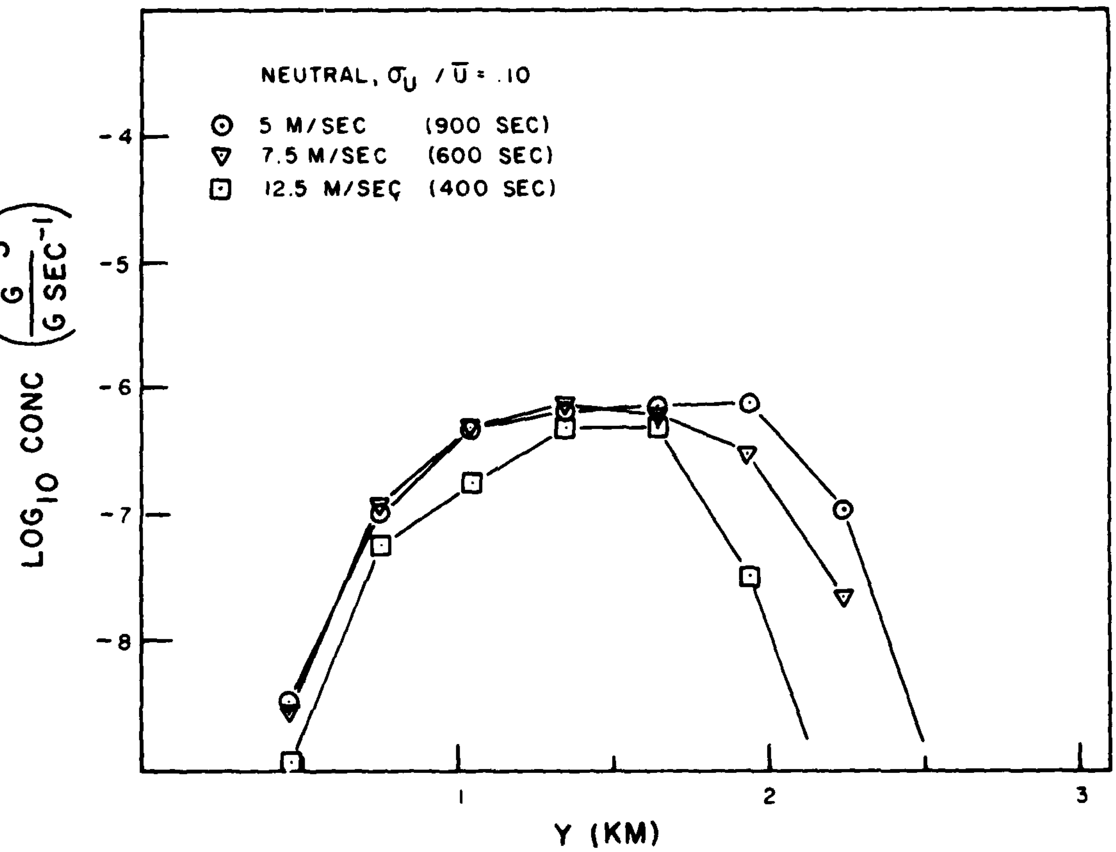


Fig. 10 — Concentration of a plume as it arrives at sensors located along the y axis as a function of the y distance from the four sources during a neutral regime

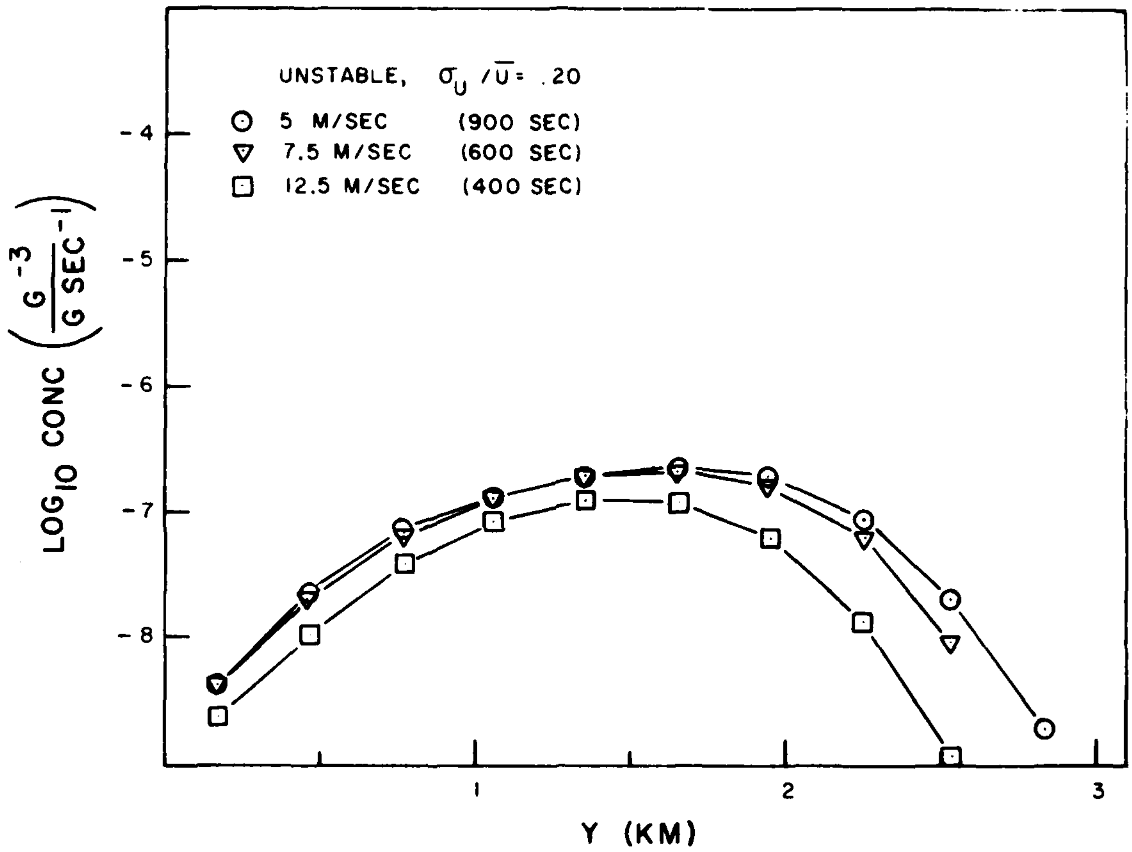


Fig. 11 — Concentration of a plume as it arrives at sensors located along the y axis as a function of the y distance from the four sources during an unstable regime

A potential problem of the generating plume being adversely affected by the turbulent wake below a helicopter had been studied at NRL (Randall, 1951). From the data obtained in this report the vertical velocity component of the helicopter's wake is plotted as the distance below the rotor in Fig. 12. We can see from this curve that there should be no vertical component of turbulent wake below 200 feet (61 m). Thus we felt confident that if the source was supported 250 feet (76m) below the rotor that this problem would be completely solved.

Budget restraints limited the experiment to 3 days of helicopter operations (July 28-30,1980) and up to six pyrotechnic devices. The plans for the operation were for a commercial helicopter to fly to SNI from the mainland to pick up the pyrotechnic device located at the end of a 250 foot (76m) steel cable (Fig. 13) and start the adjustable time delay fuse usually set for approximately 10 minutes. The helicopter would then fly to the predetermined starting position 1 or 2 kilometers upwind and hover until the ignition of the pyrotechnic. Then it would proceed at a predetermined speed and direction until the pyrotechnic was expended. At this time it recorded in photographs the growth, development and progress of these artificial fog banks.

AIR LAUNCHED PYROTECHNIC BURNERS

Three types of burners were used in the SNI tests. They are similar in a number of ways. They all consisted of a container cast-filled with a pyrotechnic material. These containers were mounted upside down to a timer assembly by means of three chains attached to eyebolts fastened in different ways to the bottom plate of the pyrotechnic container. Each was ignited electrically by means of ignitor caps fixed to the exposed surface of the pyrotechnic material and connected to the timer assembly by means of wires. Each of the chains connected with a single loop which also connected to the steel mounting plate of the timer to form a stable pyramid structure. Figure 14 shows a sketch of each of the three types of burners. A detailed description of the construction and preparation of the three types of burners is included as an appendix.

THE EXPERIMENT AT SNI

The experiment was planned for 28-30 July 1980 and was to include 12 flight hours of helicopter operation. The helicopter, based on the mainland, flew to SNI each of these mornings to meet with the research scientists located at a site inland from Red Eye Beach (Fig. 2). The pyrotechnic device was fastened by means of a 76 meter steel cable to a pilot releasable hook on the under-carriage of the helicopter. The steel cable had a breaking strength of 4000 pounds and was equiped with a swivel at the upper end. As the helicopter rose to about 70 meters, the pyrotechnic device was armed and the ignition timer set to approximately 10 minutes. The helicopter then rose to 90 meters and flew upwind across Laser Bay (Fig. 2) to the starting position (approximately 5 to 7 km upwind) and hovered at 90 meters in position until the ignition of the pyrotechnic took place. When ignition of the aerosol source was confirmed, the helicopter would travel in a course at a predetermined speed of about 25 to 35 knots to provide the moving aerosol source. At the conclusion of the burn, the helicopter would climb to 600 meters and photograph the progress of the plume as it grew in density and width and eventually crossed the target area. At the conclusion of each run, the helicopter would fly back to the landing site near Red Eye Beach and drop off the line, timer assembly and the empty pyrotechnic device before returning to the mainland.

Of the six pyrotechnic devices brought to the island, (2 of type 1, 3 of type 2, and 1 of type 3), only two gave quantitative results for our analysis. The type 2 devices had an engineering deficiency (ie, no inside container liner to prevent unwanted flame propagation) which caused premature explosions of the devices and thus could not be used for plume studies. Of the remaining three devices, we were able to get two plumes to float over the measurement site as planned. It turned out that the

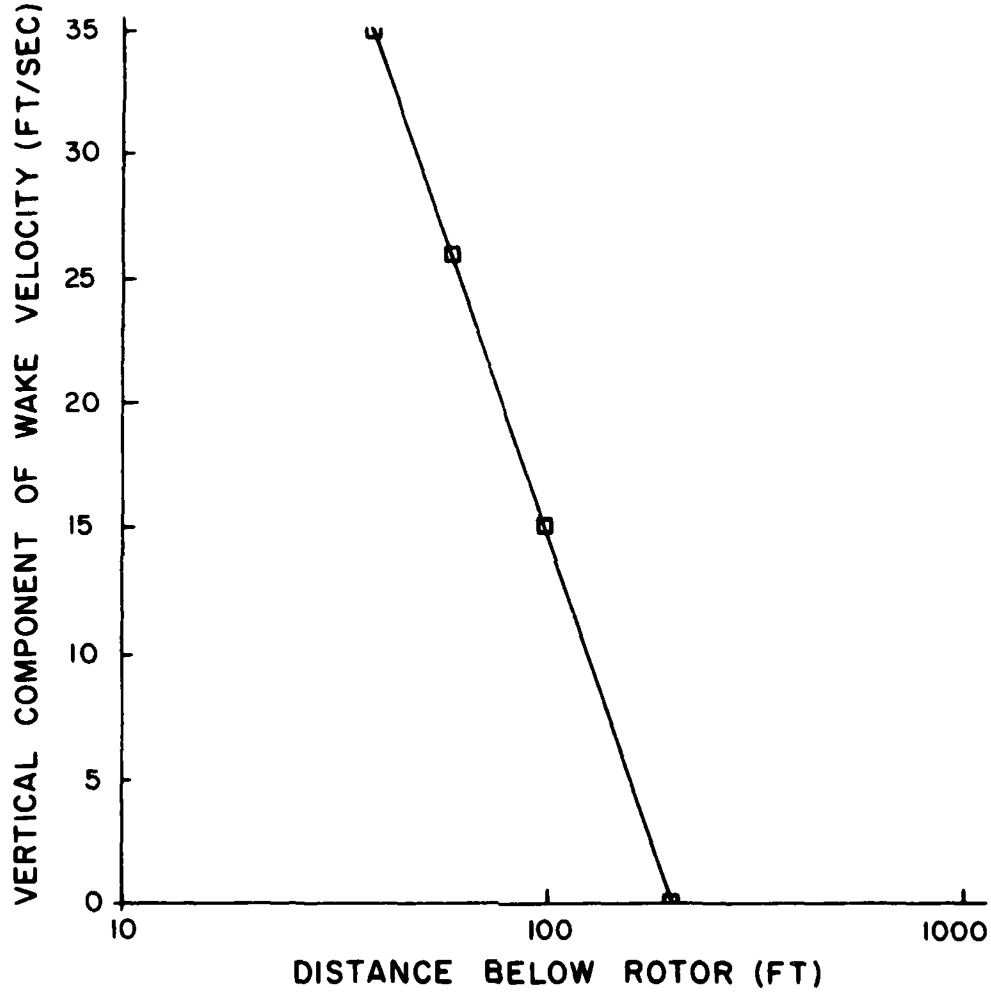


Fig. 12 — The vertical velocity in a helicopter's wake as a function of the distance below the rotors

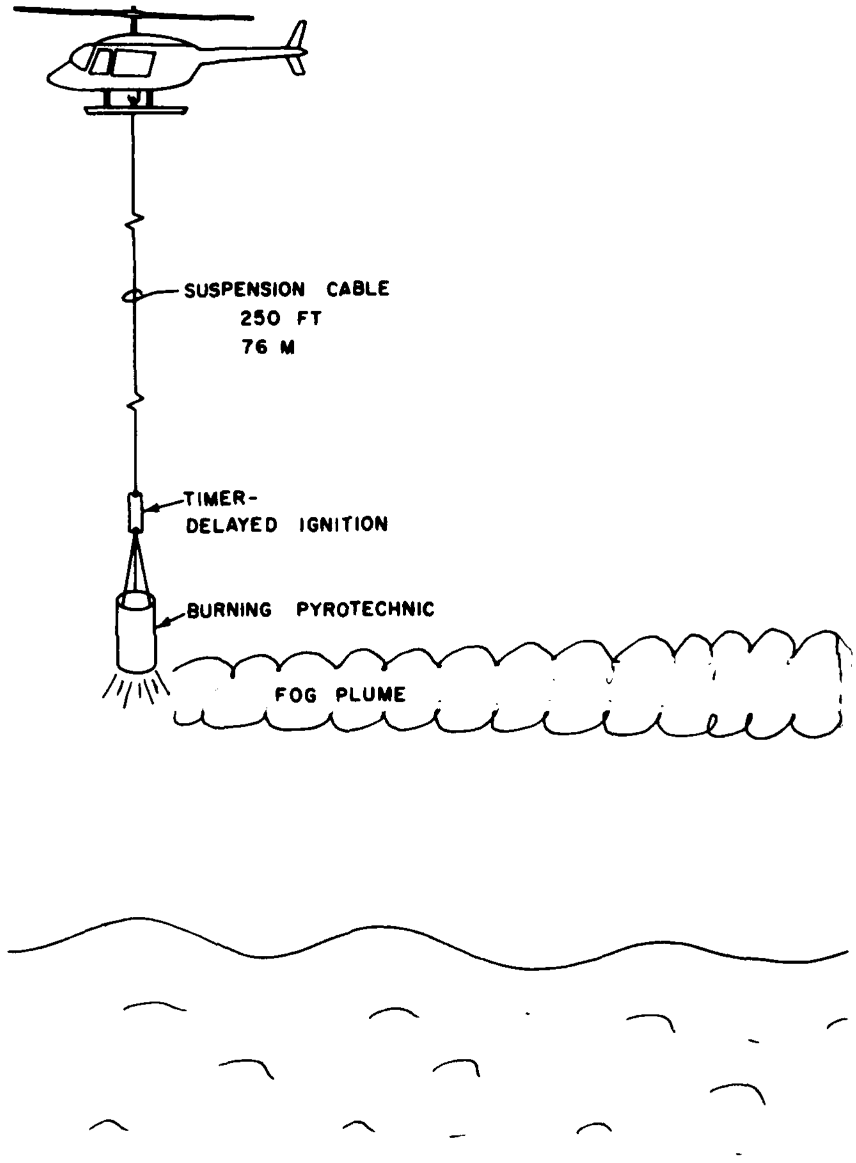


Fig. 13 — Representation of the method used for suspending the burning pyrotechnic from a helicopter

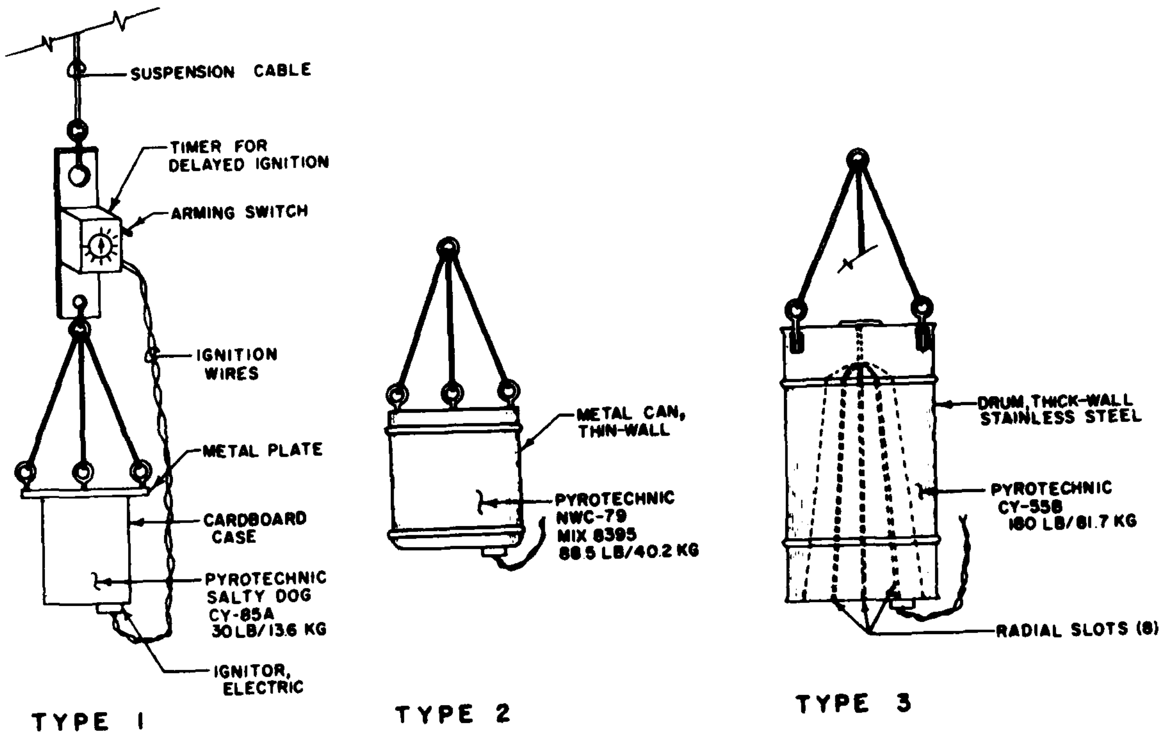


Fig. 14 — Three types of pyrotechnic burners used at SNI during the July 1980 field tests

island topography causes a considerable wind shift and plumes formed directly upwind according to wind measurements on the island, did not come to the original spot but went off to the side. It was necessary to correct the experimental procedures for these effects.

Figure 15 shows the result of a type 2 pyrotechnic burning out of control and dumping its burning contents into the ocean after an explosion had ripped up the steel container. Figure 16 shows the mangled remains of the type 2 device after one of the attempted experiments on 29 July 1980.

Figure 17 shows the proper operation of the type 3 device as viewed from the helicopter during the dispensing of the "Salty Dog" condensation nuclei on 30 July 1980. Figure 18 shows the plume growing and dispersing upwind of the test site. During this time the hygroscopic nuclei produced by the burning process are taking up water vapor from the marine layer and growing in size. In addition, because of the eddy diffusion processes in operation, the concentration of the droplets decreased and the developing cloud has spread and grown at the same time. Figure 19 is a photo taken from the helicopter showing a fog bank coming into Laser Bay just prior to the measurements of its optical properties by the aircraft and the transmissometer.

METEOROLOGICAL BACKGROUND 28 JULY 1980

The first test of the new technique was carried out for the purposes of artificially forming a large scale water fog in the moist but unsaturated marine environment. The day was overcast with otherwise ideal conditions in which to carry out the tests. The relative humidity was approximately 94% with favorable winds. The micrometeorological measurements showed the boundary layer to be slightly unstable with a net water vapor flux flowing from the ocean surface into the atmosphere. The radon measurement indicated that the air mass was definitely of marine origin and thus an excellent background into which we could introduce our artificially produced hygroscopic nuclei. Table 1 lists the various meteorological parameters that were measured on sites N,A, and B (see Fig. 2) at SNI at the time the tests were being made.

On this day neither the transmissometer nor the aircraft was in operation. Consequently it was of utmost importance to produce the artificial cloud upwind of the NRL micrometeorological tower so that the size distribution of the grown aerosol could be observed with the tower based instrumentation.

AEROSOLS OBSERVED FROM THE TOWER 28 JULY 1980

Two type 1 burners were ignited on this day. The first plume was on target over the measurement site while the second plume missed the tower because of an unexpected wind change north of the island causing the plume to veer off to the side of the stationary tower. The first plume however engulfed the tower and its instrumentation to give satisfactory results.

The size distribution observed during and after the plume with the tower PMS aerosol size spectrometer is shown in Fig. 20. These are similar in magnitude and shape with the dN/dr plots of the size distribution observed on 30 July 1980 with the aircraft instrumentation. The difference between the "during" and "after" phases is the size distributions of the artificial cloud as it grew to size over a period of approximately 8 minutes.

Figure 21 shows the size distribution grown on the pyrotechnically produced nuclei. The relative humidity of the atmosphere as measured by the various shore-based instruments at this time was 94%. When this distribution is fitted by a log-normal function the following equation represents the constants which best fit the measured data.

$$dN/dr = 46 \exp\left(-6.889 \ln^2(2.05/r)\right)$$

This curve shows the maximum value of dN/dr at $r = 2.05$ microns for a relative humidity of 94%.

R-198

Fig. 15 — Photo of the burning type 2 pyrotechnic device dropping into the ocean during the second test on 29 July 1980

R-202

Fig. 16 — Photo of the mangled remains of the type 2 pyrotechnic device after the failure of 29 July 1980

Fig. 17 — Photo of the type 3 pyrotechnic device dispensing the "Salty Dog" type nuclei as seen from the helicopter on 30 July 1980

Fig. 18 — Photo of the newly dispensed nuclei dispersing and growing in the marine layer up wind of Laser Bay on 30 July 1980

Fig. 19 — Photo of the developed fog band blowing into Laser Bay approximately 5 minutes after it was dispensed on 30 July 1980

Table 1
Station Meteorological Measurements During Artiricial Cloud Event of 28 July 1980 at SNI

Site	Operator	Tair (C)	Tdew (C)	Twater (C)	R. H. (%)	Wspd (m/s)	Wdir (deg)	Pres (mb)
N	NRL 1	16.4	15.4	—	94	5.4	267	—
N	NRL 2	16.07	15.21	—	94	4.88	—	—
N	NRL 3	16.18	15.58	17.36	96	4.82	—	—
N	PMTC	16.3	15.8	—	97	5.0	259	1007.1
A	PMTC	16.6	15.6	—	94	5.0	265	1007.0
A	PMTC	—	15.3	—	92	—	—	—
A	METERS	16.8	15.3	16.8	91	5.1	270	1007.8
B	PMTC	16.0	15.5	—	97	3.6	260	1007
	Averages:	16.34	15.46	17.1	94.4	4.83	264	1007.4

Micrometeorological calculations during 28 July 80 event

(1)	Bulk Richardson's Number	−.34 (unstable)
(2)	Profile Richardson's Number	−1.3 (unstable)
(3)	Radon Observation	4.7 Picu/m^3
(4)	Bulk Latent Heat	84 watts/m^2 up
(5)	Profile Latent Heat Flux	159 watts/m^2 up
(6)	Sky Cover	10/10

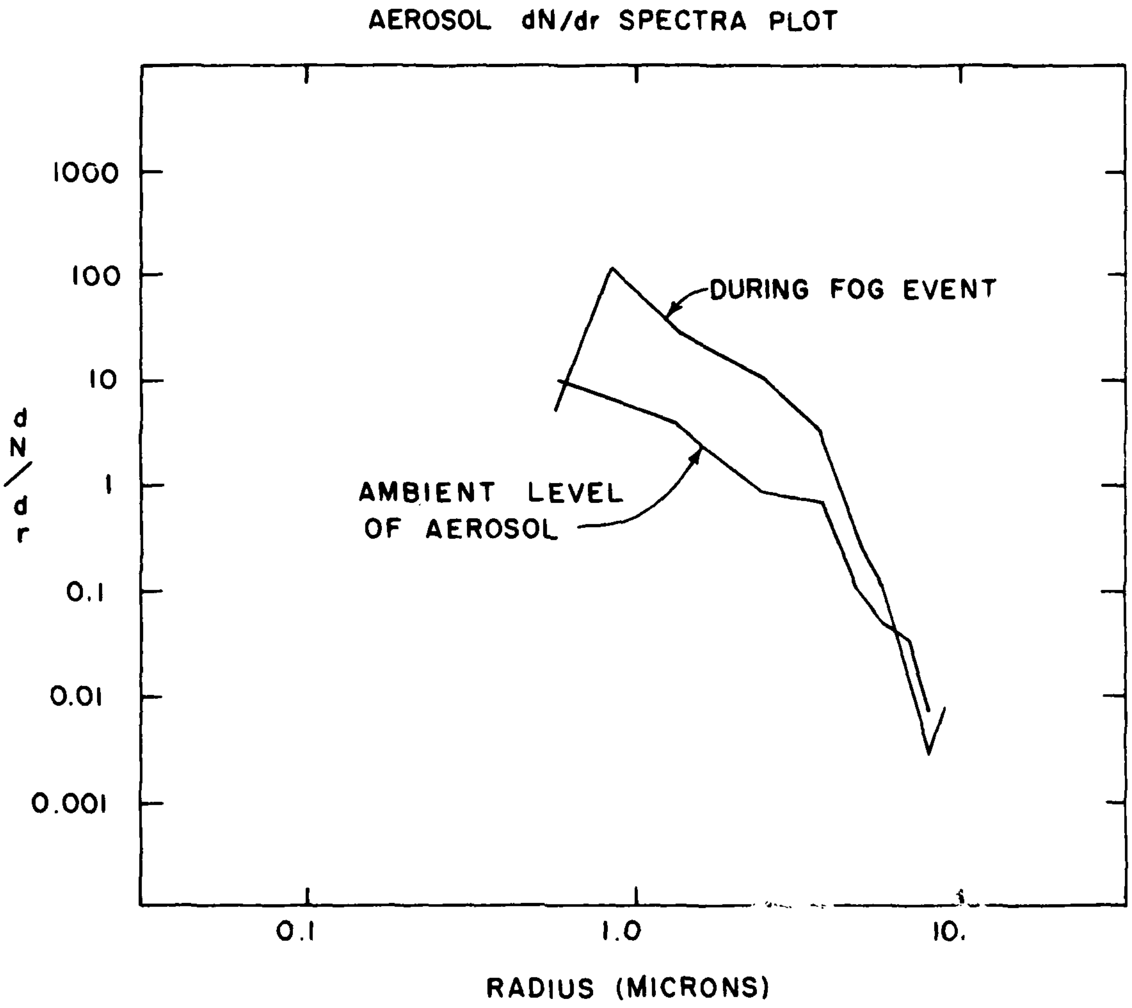


Fig. 20 — Plot of aerosol dN/dr values as a function of particle radius during and after the artificial fog event of 28 July 1980. Data taken with a PMS aerosol size spectrometer located on the NRL micrometeorological tower on SNI.

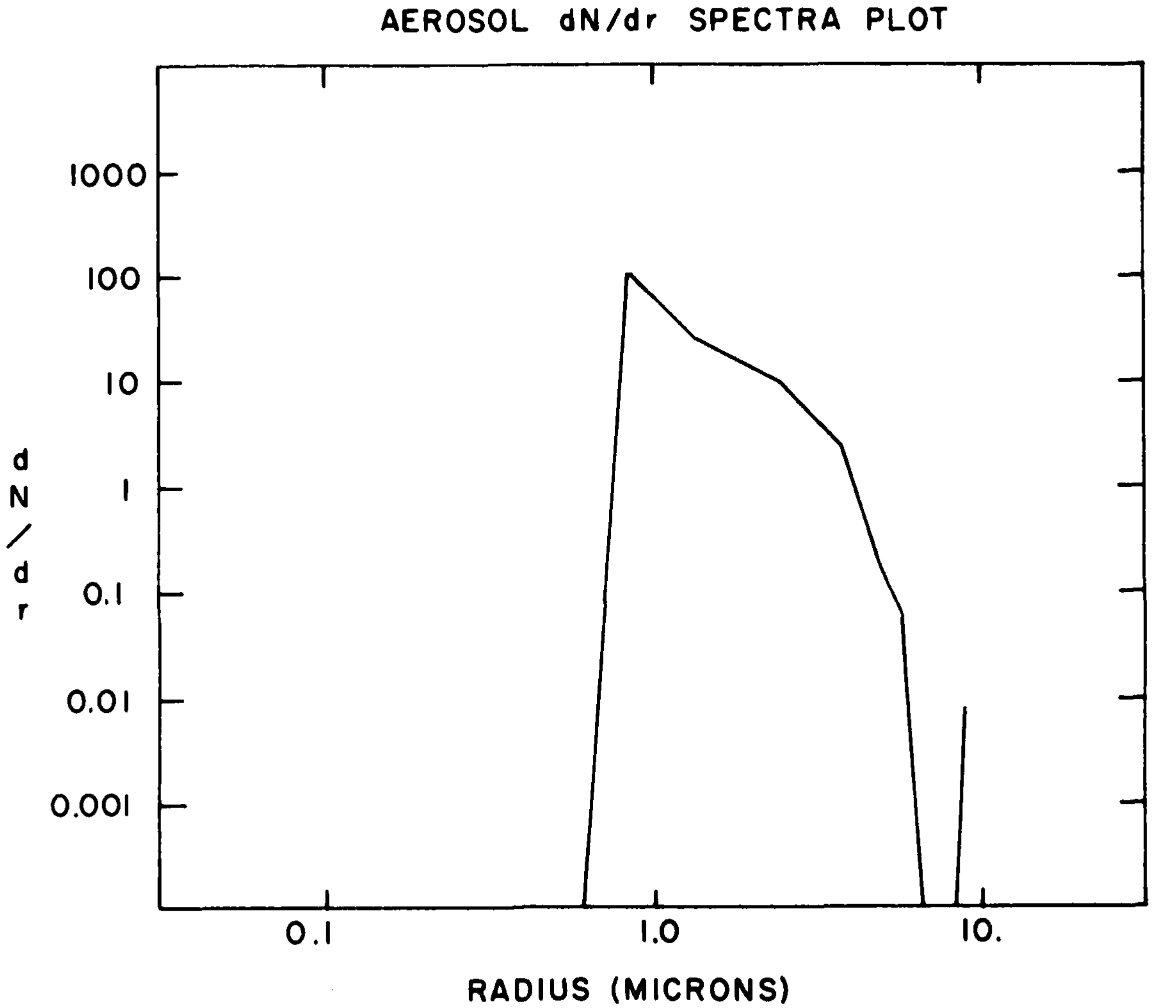


Fig. 21 — A plot of the difference between the dN/dr data obtained with the PMS aerosol size spectrometer during the fog event of 28 July 1980 and the ambient values taken shortly after the event. The instrument was located on the NRL micrometeorological tower on SNI for these measurements.

These data can also be used to calculate the aerosol extinction coefficient for various wavelengths of interest. These data shown in Table 2 indicate that the cloud has a relative increase in the aerosol extinction of a factor of 52 for 0.53 micron wavelength radiation, a factor of 68 for 1.06 micron wavelengths, a factor of 25 for 3.75 micron wavelengths, and a factor of 28 for the 10.6 micron infrared radiation. This artificial fog significantly decreased the visibility in the marine atmosphere for the shorter wavelengths and showed a definite degradation in the visibility due to aerosols in the longer wavelengths.

METEOROLOGICAL BACKGROUND 30 JULY 1980

On 30 July 1980, a second successful experiment was made. The type 3 burner was used on this day which with its mass of 180 pounds of Salty Dog pyrotechnic had the highest potential of producing a truly significant modification of the optical environment over Laser Bay on SNI.

In addition, all systems were operational and the micro meteorological observations indicated a moderately stable environment with relative humidities of 90% and a wind speed of 3.5 m/s from a direction of 302 degrees. These were perfect conditions in which to carry out the experiment.

The station meteorological measurements for this day and time are shown in Table 3. The micrometeorological calculations for the conditions at this time are also shown. Compared with 28 July 1980, the atmosphere is more stable and there is less water vapor flux being introduced into the marine boundary layer but it was still a favorable environment in which to grow fog droplets on the hygroscopic nuclei produced by the "Salty Dog" type pyrotechnic.

TRANSMISSOMETER OBSERVATIONS

The fog produced over Laser Bay on this day was observed with the 4.07 km transmission path transmissometer. (Path A-C in Fig. 2). The cloud materialized approximately 10 minutes upwind from the transmissometer path and was watched simultaneously with three wavelength transmissometers. Their operation was in the visual range, in the 3.4 to 4.2 micron wavelength and in the 8 to 12 micron wavelength infrared band. Figure 22 shows the time plot of transmittance along the path AC for the three transmissometers during the fog event. Parts of the plume were covering (at least partially) the path for a period of almost 7 minutes.

The most totally obscured wavelength was the optical band with a band pass filter of from 0.5 to 0.6 microns band width. Noticeable dips in transmission were also observed in the infrared bands. During the event, site C was completely obscured from view according to viewers at site A even though the main bulk of the fog was at a higher level.

Table 4 summarizes the transmission results of the artificial fog by presenting the total transmittance measured at the site for the three bands of wavelengths. These include "before" and "during" values as well as the total and molecular transmittance calculated for the wavelengths using the LOWTRAN 4 calculations with the local meteorological measurements as inputs.

AIRCRAFT OBSERVATIONS

There were two passes by the NOSC aircraft which penetrated the fog just before and during the time the transmissiometer path was obscured. Pass zero was from 11:52:55 until 11:54:15 and was typical of the background data. Pass one was from 12:08:10 until 12:08:58 and pass two was from 12:10:39 until 12:11:28. The aircraft during these passes was flying from site C to site A at the altitude of the center of the cloud (somewhat over 15 meters) A second background measurement, during pass three, was taken over the path C-B-A from 12:23:01 until 12:23:49. These data are representative the background over the site after the cloud bank had dissipated itself over the hot dry island land mass.

Table 2
Knollenberg Aerosol Data
28 July 1980

Clear Air	Wavelength (microns)	Scat. Coef. (/km)	Vis. Range (km) (aerosols)
N = 30/cc lambda = 0.5 – 45 microns			
	0.53	0.07	55
	1.06	0.06	65
	3.75	0.02	—
	10.6	0.005	—
Artifical Fog			
N = 1030/cc			
	0.53	3.7	1.
	1.06	4.1	0.9
	3.75	0.5	8.
	10.6	0.14	28.

Table 3
Station Meteorological Measurements During
Artificial Cloud Event of 30 July 1980
at SNI

Site	Operator	Tair (C)	Tdew (C)	Twater (C)	R. H. (%)	Wspd (m/s)	Wdir (deg)	Pres (mb)
N	NRL 1	17.6	16.4	—	92	4.2	284	—
N	NRL 2	18.1	16.7	—	91	3.45	—	—
N	NRL 3	18.3	16.7	17.6	91	3.31	—	—
N	PMTC	18.1	17.9	—	99	3.4	305	1010.2
A	PMTC	18.9	17.5	—	91	3.5	307	1010.4
A	PMTC	—	16.8	—	87	—	—	—
A	METERS	19.6	17.5	17.7	87	3.5	310	1011.1
A-C	NOSC	18.7	16.3	18.5	85	—	—	—
Averages:		18.5	17.0	17.93	90.4	3.49	302	1010.3

Micrometeorological calculations during 30 July 80 event

(1) Bulk Richardson's Number	+.04 (stable)
(2) Profile Richardson's Number	−0.9 (unstable)
(3) Radon Observation	3.8 $PiCu/m^3$
(4) Bulk Latent Heat	84 $watts/m^2$ up
(5) Profile Latent Heat Flux	47 $watts/m^2$ up
(6) Sky Cover	5/10

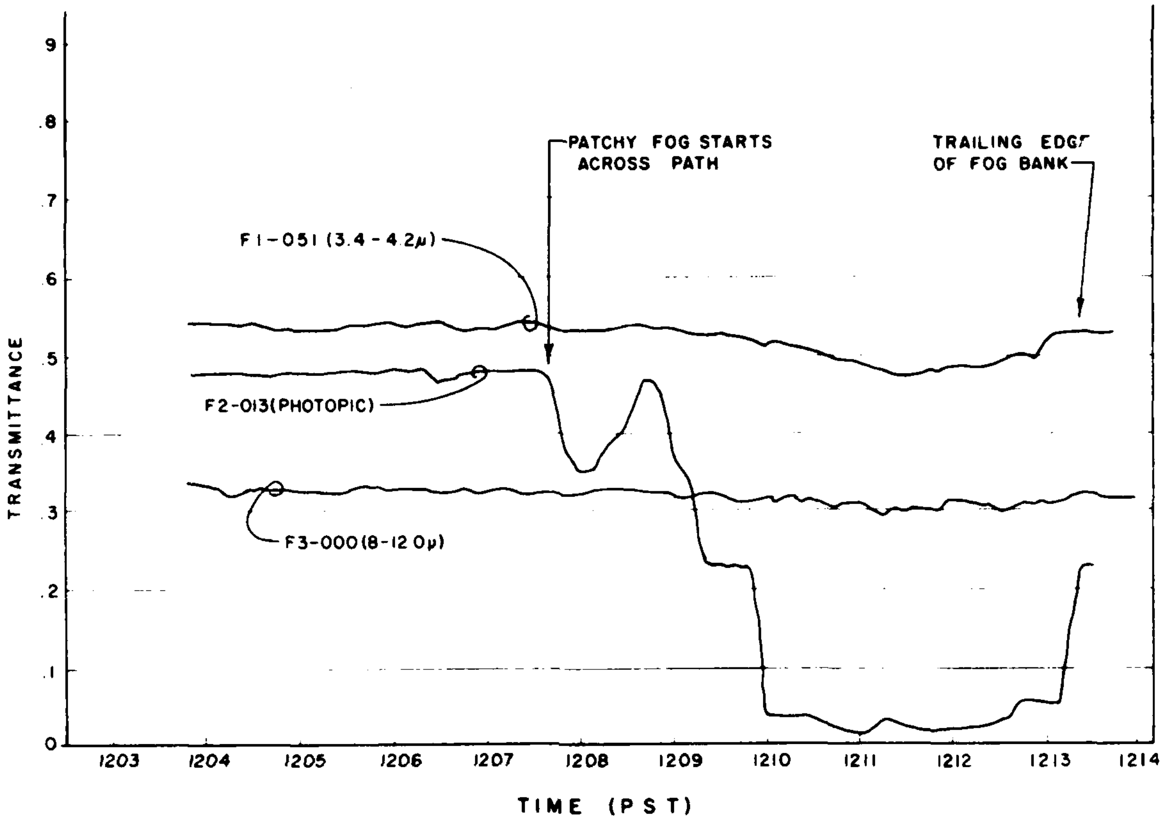


Fig. 22 — Time plot of transmittance over path AC on SNI during fog event of 30 July 1980 for three bands of optical energy

Table 4
"Salty Dog" Artifical Aerosol Drop Test, San Nicolas Island,
Laser Bay, July 30, 1980 (Highmode)

Time: 1200-1300 PST; Transmission Path: Site A to Site C (4.07 km)

***** Measured Transmittance T_t *****				LOWTRAN 4 TRANSMITTANCE			
				NRL MET.		PMTC MET.	
Filter	Before Aerosol Drop	After Aerosol Drop	% Decrease	T_t	T_{MOL}	T_t	T_{MOL}
F1-013 (Photopic)	.468	.021	95.5	.485	.964	.482	.963
F2-051 (3.4-4.2μ)	.541	.484	10.1	.556(R)	.603	.555(R)	.599
F3-000 (8-12.0μ)	.323	.314	2.8	.296(R)	.320	.294(R)	.318

NOTE: T_t = Total Transmittance = $T_A T_{MOL}$
T_{MOL} = Molecular Transmittance (using eith PMTC or NRL MET data)
T_A = Aerosol Transmittance
(R) = Rural aerosol model used in calculation

The above data may not represent the densest part of the cloud because the materal was dispensed at too high of a level with respect to the transmission path for maximization of the effect.

During each of these flights a PMS, aerosol size distribution instrument was in operation making measurements of aerosol concentration from a radius of 0.3 microns to 14.2 microns. These data were automatically put into 32 size classifications and stored for future calculations.

From these data, size distributions are made as well as the aerosol extinction coefficient calculated for several wavelengths of radiation. For these calculations the following values of the fractive index were used:

Lambda = 0.53(microns).... N=1.332 -j*0.162E-8
Lambda = 1.06(microns).... N=1.367 -j*0.601E-4
Lambda = 3.75(microns).... N=1.398 -j*0.29E-2
Lambda = 10.59(microns)... N=1.271 -j*0.522E-1

The transmission of light between two points can be expressed either in transmittance or extinction coefficients. In terms of the transmittance, a pure number reflects the fraction of incident flux which remains in the beam after passing through a unit thickness of atmosphere. Extinction coefficients express the process of scattering and absorbtion that may be going on in the medium. The quantity most easily obtained from the transmissometer is the transmittance of a particular band of radiation as influenced by the spectral characteristics of its source and receiving optics. On the other hand, those looking at the aerosols themselves fine it more instructive to talk about a scattering or an absorption coefficient for a particular wavelength from a certain distribution of aerosols.

The aerosol size distribution can be converted into a scattering coefficient for a single wavelength by Mie theory. The molecular absorption terms can be obtained from local meteorological measurements and a computer on which to run the LOWTRAN 4 codes. For the purposes of this report however the actual transformation from one set of parameters into the other set is not necessary. It is sufficient to say that they can (to within experimental error) be computed into the equivalent sets of parameters. What is important for this report is the spectral response of each of these techniques to the artificial cloud which we generated as compared with the ambient conditions existing at that time.

Figure 23 shows the size distribution of aerosol scatterers before, during and after the artificial fog event. These data are similar to that obtained by the PMS instrument on the NRL tower on 28 July 1980 described earlier.

Passes 0 and 3 show the background aerosol size distribution and, as they are almost identical although taken more than 30 minutes apart, we can be assured that the background conditions are relatively unchanging throughout the time scale of the experiment. Note that the apparent noise in the dN/dr curve for the very large particles is due to statistical fluctuations caused by the relatively small number of particles in these size classifications and the short sampling period. Pass one is inconclusive because the aircraft was not within the cloud for the whole period. This is evident when comparing the time history of the passes as seen in the calculated extinction coefficients for the various wavelengths as a function of time when the aircraft traversed the paths. Figure 24 is the time history of pass 1 and shows clearly that artificial fog was not measured continuously throughout the 48 second flight time. In contrast is pass 2, which only two minutes later had most of its time history within the artificial cloud (Fig. 25). The data from this pass then is the best available sampling of a mature Salty Dog cloud as it developed over a period of approximately 10 minutes in the marine environment.

Thus, in order to see the size distribution of the artificial droplets, we may subtract from the dN/dr data in pass 2 the background values from either pass 0 or 3. The results are shown in Fig. 26 and clearly depicts the size distribution of the artificial aerosol component which was introduced into the marine atmosphere. If this curve is represented by a log-normal size distribution, it would have a

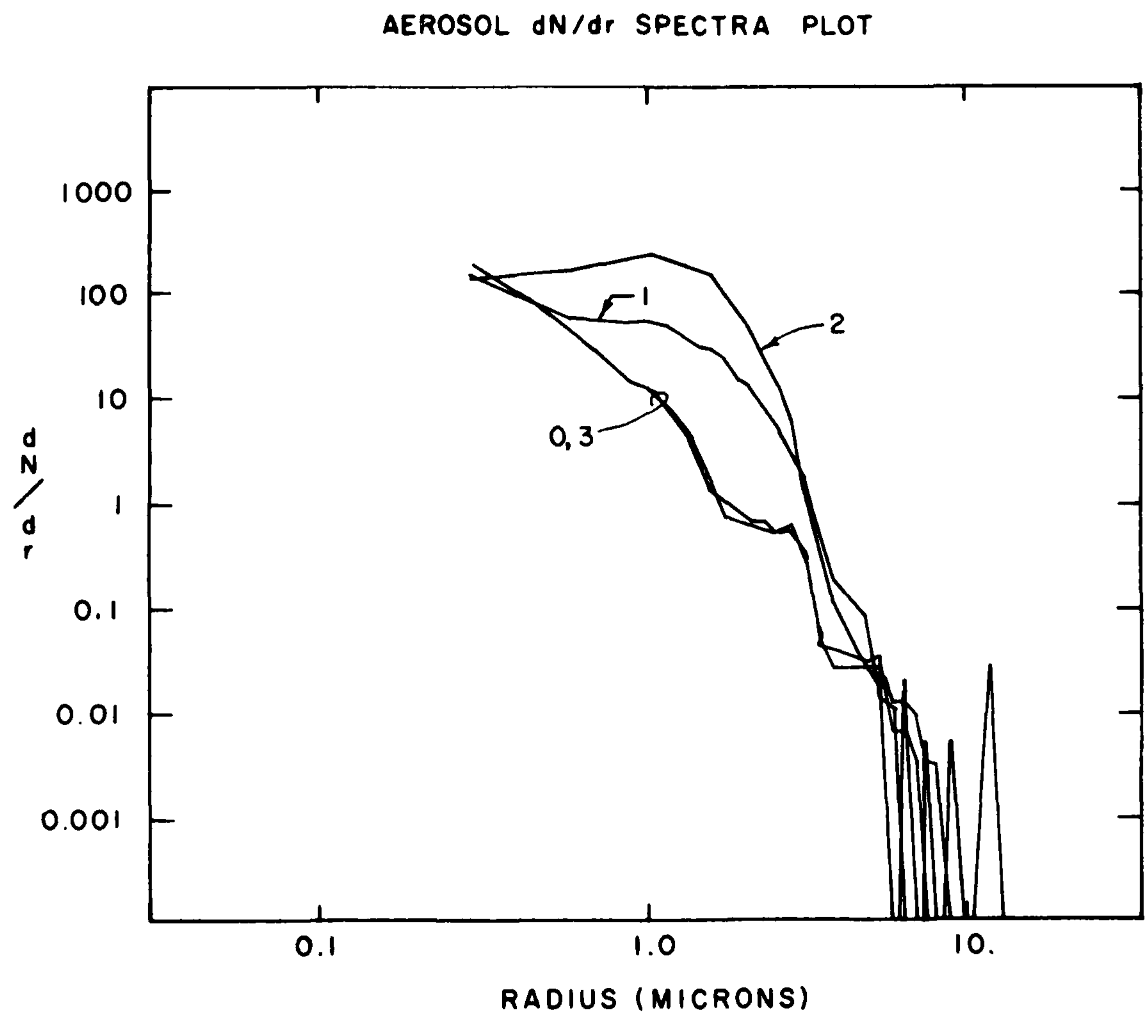


Fig. 23 — Plot of the aircraft measured dN/dr size distribution before, during and after the artificial fog event of 30 July 1980

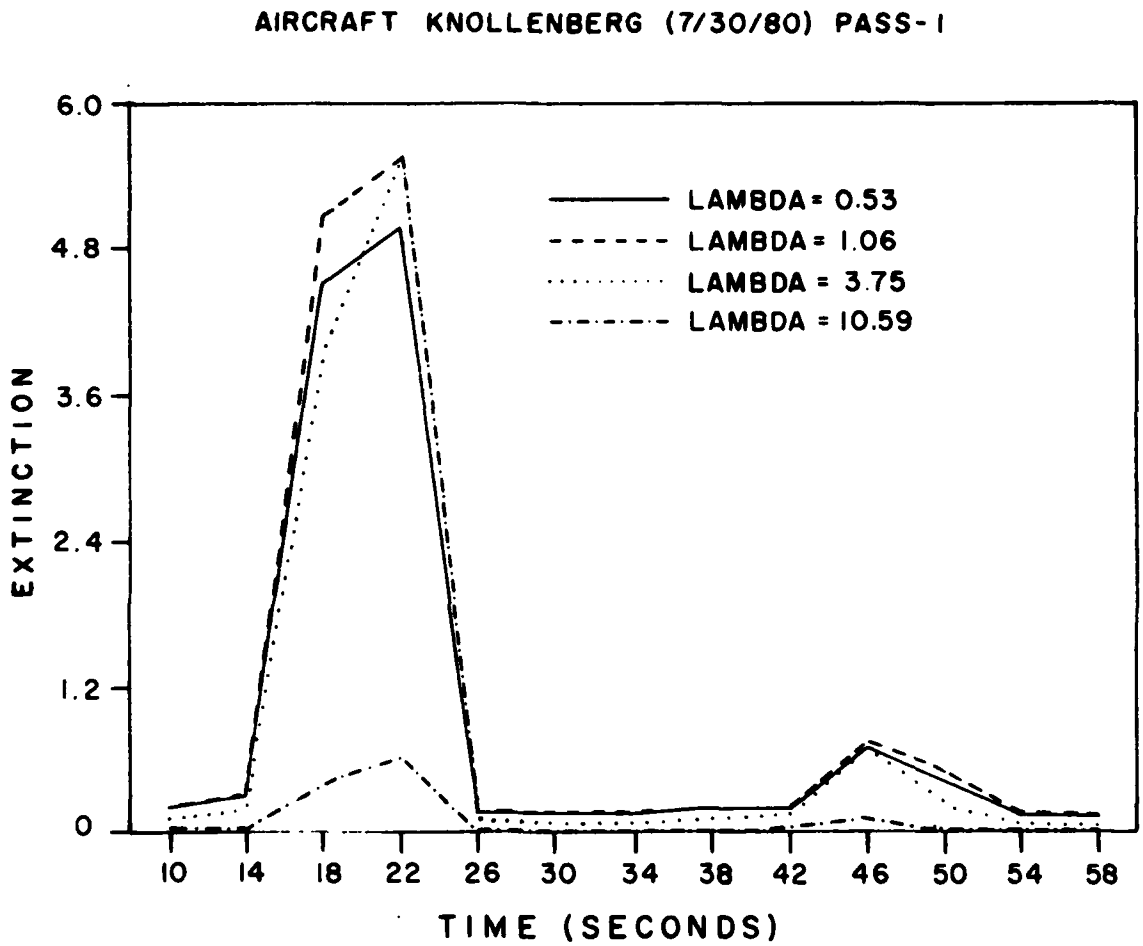


Fig. 24 — The time history of the calculated extinction coefficients for four wavelengths from the aerosol data obtained by the NOSC aircraft on pass 1 of 30 July 1980

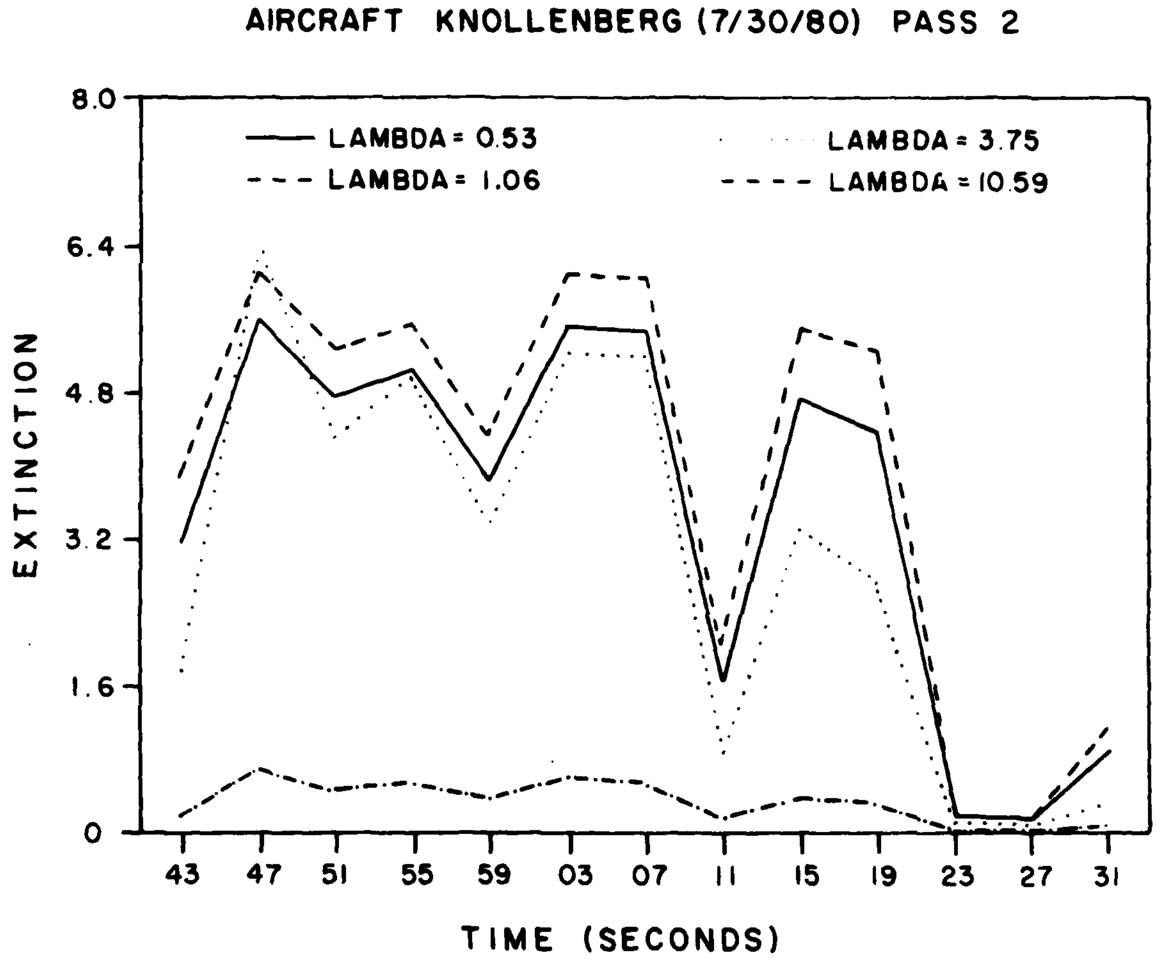


Fig. 25 — The time history of the calculated extinction coefficients for four wavelengths from the aerosol data obtained by the NOSC aircraft on pass 2 of 30 July 1980

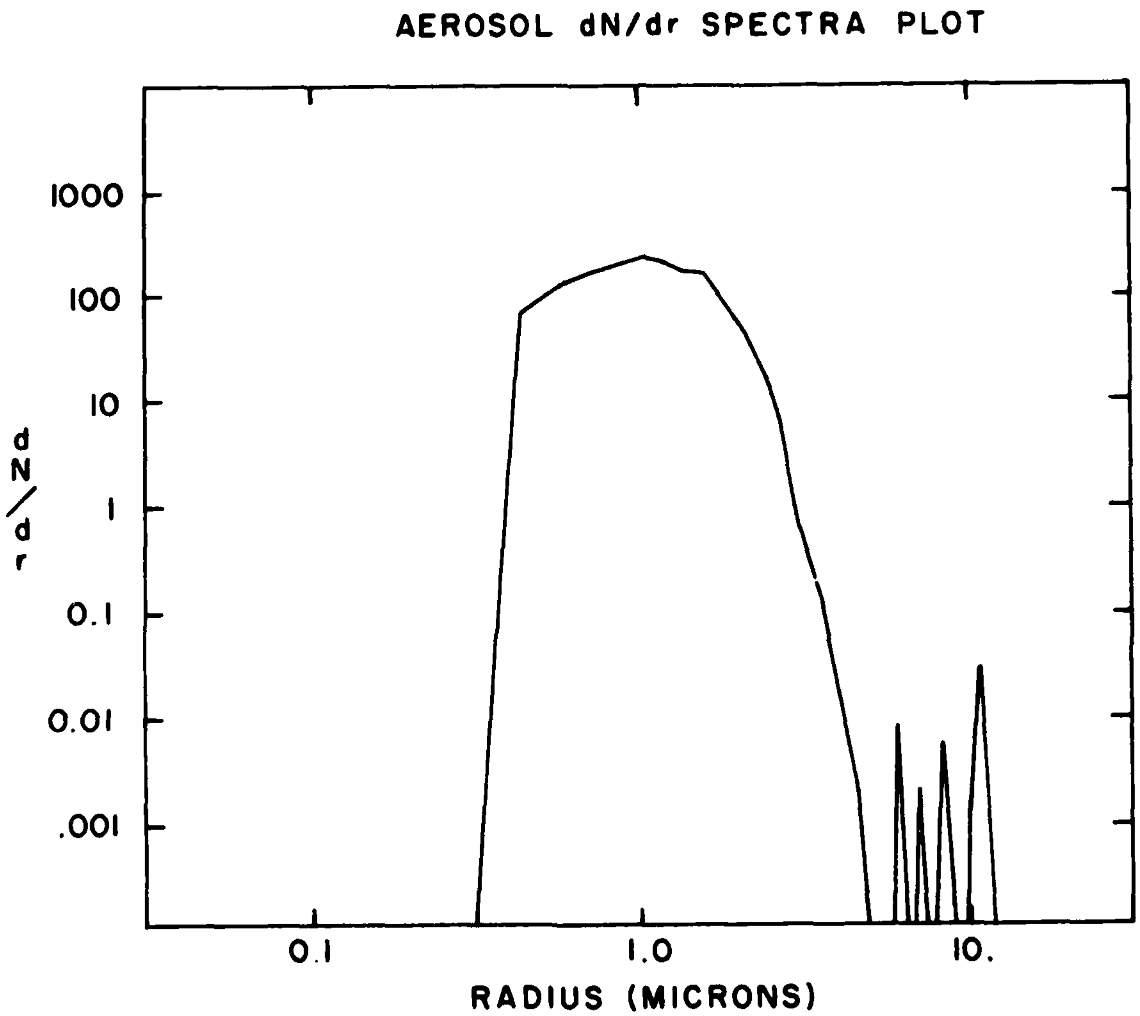


Fig. 26 — Plot of the difference between the dN/dr data obtained with the airborne PMS aerosol size spectrometer during the fog event of 30 July 1980 (pass 2) and the ambient values taken on pass 0

maximum value of dN/dr at a radius of 1.197 for a relative humidity measurement of 85% (at the aircraft making the measurement) or 90% for the average of all available humidity sensors in the area. The best fitting log-normal curve for these data is shown in the following equation:

$$dN/dr = 623.6 \exp(-7.5 (\ln^2(1.197/r))).$$

The calculated aerosol extinction data during pass 2 as shown in Fig. 25 are in sharp contrast to the background data for pass 3 shown in Fig. 27. According to these data, the artificially produced cloud increases the aerosol extinction coefficient by a factor of 30 (over background) for the visible and 1.06 micron wavelengths, a factor of 60 for the 3.75 micron wavelengths, and a factor of 30 for the 10.59 micron radiation. Even though the relative extincton is high for the four wavelengths, the absolute extinction data due to aerosols is not high in the 10.59 micron wavelength region when compared with the visible region.

The meaning of these results however can be best illustrated by the data presented in Fig. 28. Here are shown the ratio of the extinction coefficients at various important wave lengths to the extinction coefficient in the visible band. This plot shows in a relative sense how the results of this field experiment on SNI compare with the standard white phosphorus smoke and other field experiments with alkali chloride smokes. The SNI data will be plotted side by side with some results of the recent Smoke Week III results held at Eglin AFB, Florida. The white phosphorus smoke data plotted in the figure is the average of four trials during the period. The individual points however did not show much variation as the relative humidity went from a low of 58% to a high of 94%. The alkali chloride smokes during the Smoke Week III are shown in the figure by the bars with the vertical shading. Alkali chloride smokes ("Salty Dog" type pyrotechnic) used in the SNI field test reported in this report are shown by the horizontal shaded bars. In general the alkali chloride smokes do show a distinct relative humidity variation as expected. The higher the relative humidity the better is the ability of the droplets nucleated on alkali chloride particles to block optical transmission.

The data shows however that given a sufficient ambient relative humidity (R.H. > 77%) that the alkali chloride smokes perform well as an obscurant when compared with the standard white phosphorus material.

One interesting feature of the data is the extremely high ratio of the extinction coefficient at 3.5 microns to the visible from the aircraft flight data on the fully developed "Salty Dog" cloud. This particular cloud was allowed to develop in a true marine atmosphere for a greater length of time than any of the other test clouds and may indicate that the alkali chloride smokes require a greater development time in an atmosphere with ample moisture supplies and mixing processes in order to produce the desired larger droplets required to scatter the longer wavelength radiation. These data (even the extinction at 10.6 microns) show the alkili chloride smokes to be comparable with that of the white phosphorus smoke.

CONCLUSIONS

The SNI experiments provided several valuable facts. First of all, it is possible to produce a fog plume with the use of a pyrotechnical device for generating hygroscopic nuclei in the marine atmosphere on a militarily significant scale. Such a fog, in view of its non-toxic nature, would certainly be an environmental improvement over present obscurant devices in use. This would be especially true for training exercises where the inhalation of potentially harmful aerosols is not necessary. See for example Sax (1975) where it is stated that:

> "The long continued absorption of small amounts of phosphorus can result in necrosis of mandible or jaw bone, and is known as phassy-jaw."

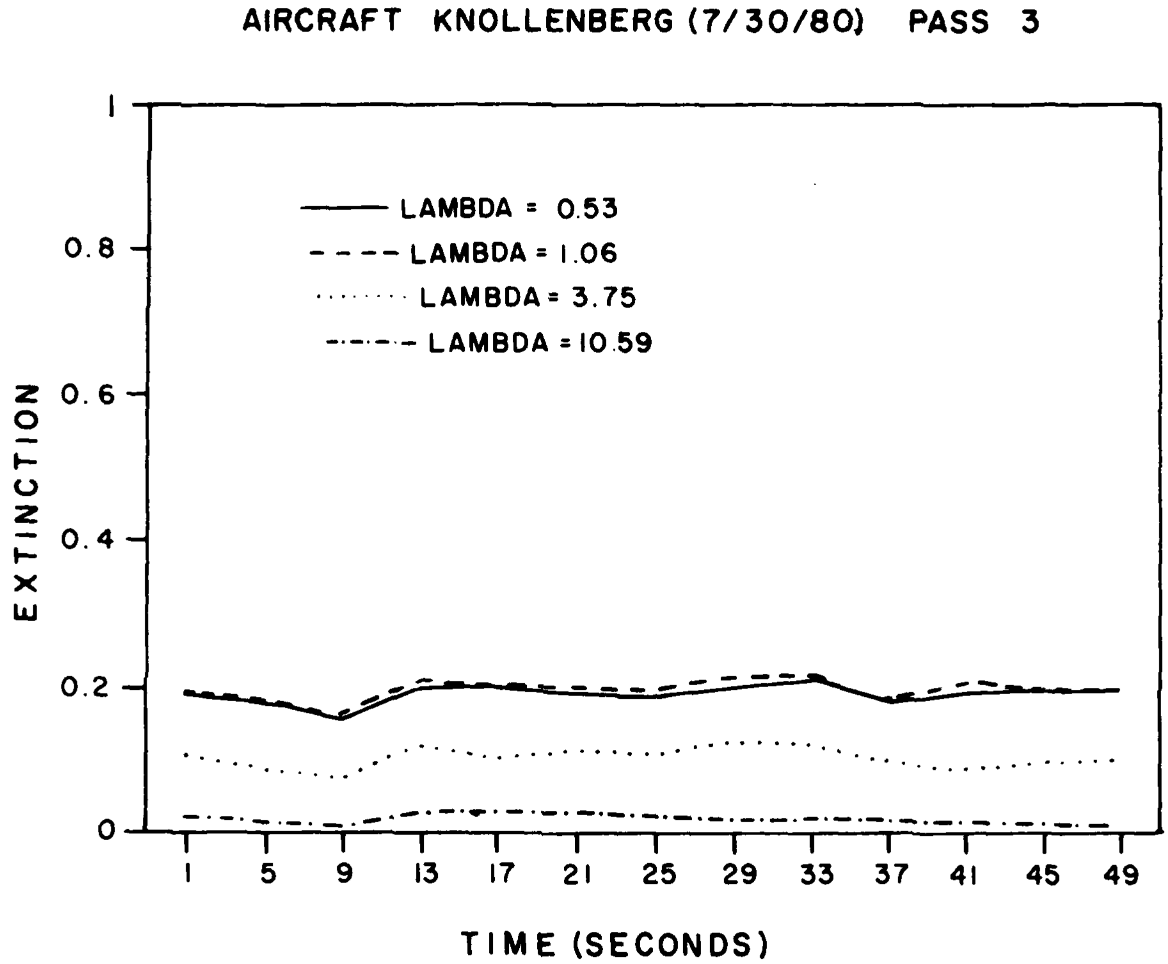


Fig. 27 — The time history of the calculated extinction coefficient for four wavelengths from the aerosol data obtained by the NOSC aircraft on pass 3 of 30 July 1980

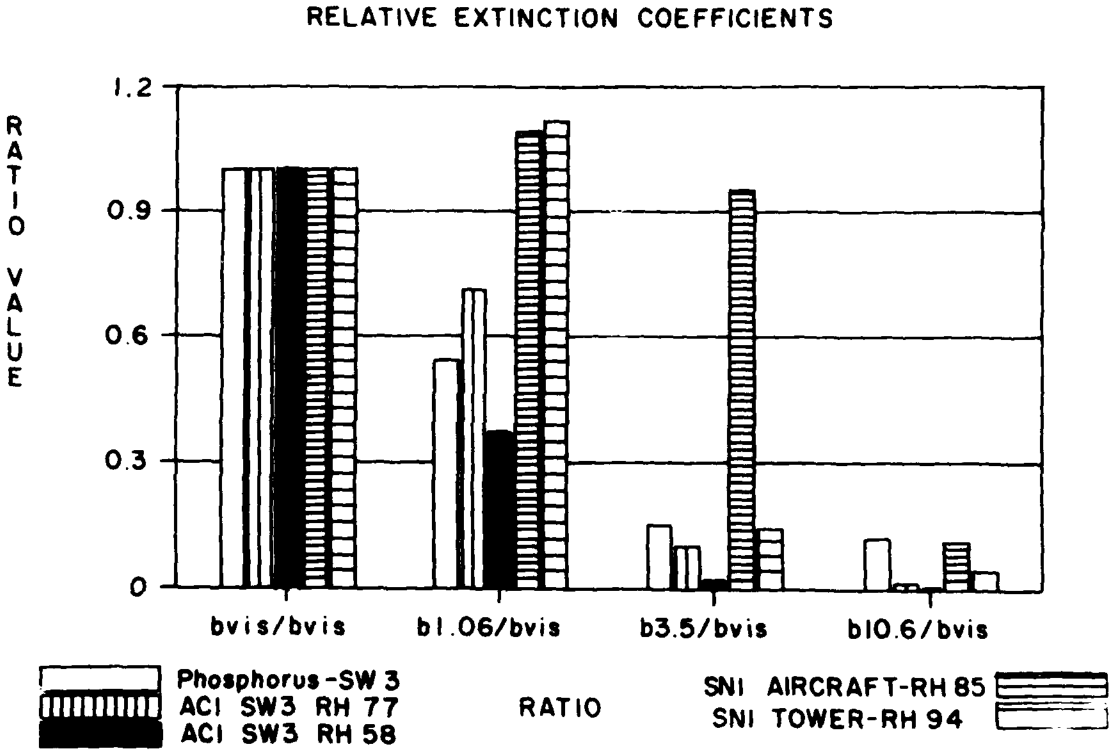


Fig. 28 — A comparison of relative extinction coefficients at various wavelengths with respect to the extinction coefficient at visible wavelengths for an average of four phosphorus smokes at Smoke Week III and four alkali chloride smokes. The relative humidity and experiment site for the alkali chloride smokes are given in the figure key.

The fogs produced by this method show a significant reduction in the optical transmission characteristics of the atmosphere in the visible and even out through the 3-5 micron wavelength infrared range on a scale comparable with phosphorus smokes.

The fog droplet size distribution differs somewhat from natural fogs (Garland, 1971) in that they do not show significant numbers of droplets with radii above 10 microns. The droplet size distribution represented by the dN/dr values as a function of the droplet radius can be represented by a log-normal distribution. The maximum value of this distribution is expected to be, and indeed seems to be, a function of the ambient relative humidity. Artificial fog production at low ambient relative humidities can be improved by at least two methods. Gathman et.al. (1979) generated droplets in a high relative humidity environment and thus grew the nuclei into larger sizes which were then coated with a surfactant material to stabilize their sizes against further evaporation before they were introduced into the drier atmosphere. Mathews and St.Amand (Mathews and St.Amand, 1981) through a change in the chemical composition of the pyrotechnic material have been able to grow aerosols at lower relative humidities.

The SNI experiment showed the importance in the technical construction of the physical pyrotechnic burner in both its reliability and its burning rate.

This technique provides excellent results in the visible and near IR, but could be improved if the hygroscopic nuclei could be produced in large dry sizes by some form of control of the burning and generation process. These larger nuclei would grow in the ambient marine atmosphere (such as experienced at SNI) into larger size droplets and would thus increase the extinction of infrared radiation in the longer (8-12) micron wavelength bands.

ACKNOWLEDGMENTS

The authors wish to thank especially Dr. H. Rosenwasser of NavAir code 310a for his support of the hygroscopic aerosol research and for his personal encouragement of these efforts.

This experiment could not have been accomplished without a large amount of cooperation within the Naval scientific community. The authors wish in particular to thank Dr. Juergen Richter of NOSC who is the block manager of the Navy's EOMET program for his cooperation in allowing this experiment to take place in conjunction with the EOMET highmode operation at SNI. Thanks are also due to Dr. Alexis Shlanta of NWC who was the chief scientist in the field during the high mode operation for his excellent help and cooperation during these tests.

Thanks are due to E. J. Mack and J. T. Henley of Calspan Corporation and to Dr.'s K. Davidson and J. Hojstrup of NPS for their help in the plume studies and its impact on the planning of the experiment. The smooth operation of the helicopter phase of the effort was due largely to the efforts of Mr C. Elliot of PMTC.

Special thanks are due to the following people for making many of the measurements discussed in this report. The measurements of the background meteorology on the island was due to the efforts of Dr. J. Rosenthal and his people at PMTC. The micrometeorological measurements were made by the efforts of T. Blanc of NRL.

We greatly appreciate the data obtained by the transmissometer on the island which were made by Dr. G. Mathews and his group at PMTC who were funded under the OSP project of Dr. J. Wunderlich of NWC. We appreciate the efforts of Dr. R. Jeck of NRL in his measurements of the aerosol from the micrometeorological tower. Finally perhaps the greatest debt is owed to Dr. D. Jensen of NOSC for his excellent efforts in obtaining aerosol particle data inside of the artificial clouds with the instrumented aircraft.

REFERENCES

1. Gathman, S. 1980a; Field Test of Stabilized Pyrotechnically Generated Water Fogs; "Artificial Aerosols," Edited by Deepak, A. and Ruhnke, L.H., NRL Memo Rpt. 4197, p 22.

2. Gathman, S. 1980b; "Field Experiments with Artificial Aerosols"; Research Program Review: Energy conversion, non-propulsive aspects, fuels and pyrotechnics; Naval Air Systems Command Research and Technology Group, pp 151-173.

3. Blanc, T.V. 1978; "Micrometeorological Data for the 1978 Cooperative Experiment for West Coast Oceanography and Meteorology (CEWCOM-78), Vol I," NRL Memorandum Rept. 3871.

4. Larson, R.E. and R.K. Jeck 1981; "Atmospheric 222Rn Measurements at San Nicolas Island during 1980," NRL Memorandum Rept. 4099.

5. Gathman, S.G., Julian, B.G., Markson, R.K. and Sedlacek, J. 1979; Field Test of the Stabilization of Supersized Water Droplets Condensed on Pyrotechnically Generated Hygrosopic Nuclei, NRL Memo Rpt. 4059, pp 28.

6. Gathman, S.G., B.G. Julian, R.K. Markson, and J. Sedlacek 1981; "Field Comparisons of Pyrotechnically Generated Fogs," NRL Memorandum Rept. 4443.

7. Hanley, J.T. and E.J. Mack 1980; "A Laboratory Investigation of Aerosol and Extinction Characteristics for Salty Dog, NWC29 and NWC78 Pyrotechnics," Calspan Rept 6665-m-1.

8. Mikkelsen, T. 1979; Simulation of Obscuration Smoke Diffusion; Danish Defense Research Establishment/Ris0, Physics Department Meteorology Section, pp 73.

9. Randall, D.L. 1951; Determination of Extent of Turbulent Wake Below a Helicopter, NRL Letter Rpt. 3823-544A/51.

10. Garland, J.A. 1971; "Some Fog Droplet Size Distributions Obtained by an Impaction Method," Quart. J. R. Met. Soc., v 97, pp 483-494.

11. Mathews L.A. and P. St. Amand 1980; "Alkali Halide Screening Smoke Formulations," Research Program Review: Energy Conversion, non-propulsive aspects, fuels and pyrotechnics; Naval Air Systems Command Research and Technology Group pp 109-128.

12. Sax, N.I. (1975); "Dangerous Properties of Industrial Materials," fourth edition; Van Nostrand Reinhold Co., New York, pp 1258.

APPENDIX

The techniques for the construction of the pyrotechnic burners is not readily available and may be in danger of being forgotten. The construction techniques, worked out at NWC over a decade ago, ought to be recorded so there will be a reference available to future workers in this field. Thus, this appendix will discuss the details of the construction of the three types of burners used in this field test and should provide an example for the building of future airborne pyrotechnic burners.

The type 1 burner consisted of 30 pounds of CY85A material cast into a three gallon cardboard ice-cream container. This container was in turn fastened to a metal plate containing the eyebolts.

The type 2 burners were prepared in the following way. Thin-walled metal containers with three eyebolts fixed to the bottom were first cleaned with paint thinner and then with acetone. They were primed with a coat of Seaguard Blue and then lined with a thick coat of paint (LR-28, mix 8400). This was allowed to cure overnight at 135 degrees F. They were then cast solid with the newer pyrotechnical material NWC-79, mix 8395. The net weight of these burners was 88.5 pounds. This procedure should be avoided because it doesn't allow for liners in the containers. The material is subject to unwanted flame propagation and possible explosion.

The recommended procedure is to construct the burner in the same manner as was the type 3 burner used in this experiment. The basic container was a large stainless steel drum. It differed from the others in that it had a hollow core (see Fig. A1) in order to allow both for expansion of the material and for an increased burning surface for a higher burning rate. This was accomplished by fastening along the axis a floor flange and a 5 inch piece of 1 1/4 inch iron pipe capped with a pipe cap drilled with a 1/8 inch hole in its center. This was to act as a centering device for mounting a molding mandrel during the casting process. The interior of the type 3 burner was prepared by first cleaning the interior with acetone and then brush priming with Stanley (4CX415) primer over the interior of the drum. A modified L-C-2 liner (0.2 inch thick) was line spun into place and cured at 180 degrees F. A bottom coating of modified ST-723 was cast to a thickness of 1" to the bottom of the drum and cured at ambient temperature. Again this surface was primed with the Stanley primer and a bottom liner of modified L-C-2, 1/4 inch thick was cast against the primed ST-723 surface and again cured overnight at 180 degrees F. A 24 inch spherical motor mandrel was fixed along the axis of the drum from the bottom pipe cap and its centering hole through the open end of the container.

Then CY-85B pyrotechnical material was gravity cast into the drum and cured for 4 days at 135 degrees F. After the shore hardness measured over 30, the burner was removed from the oven and allowed to cool. When ambient temperatures were reached, the mandrel was removed from the drum and the drum sealed until it was to be used. The total weight of the type 3 burner was 180 pounds. The three equally spaced eyebolts were strapped to the outside of the drum for support.

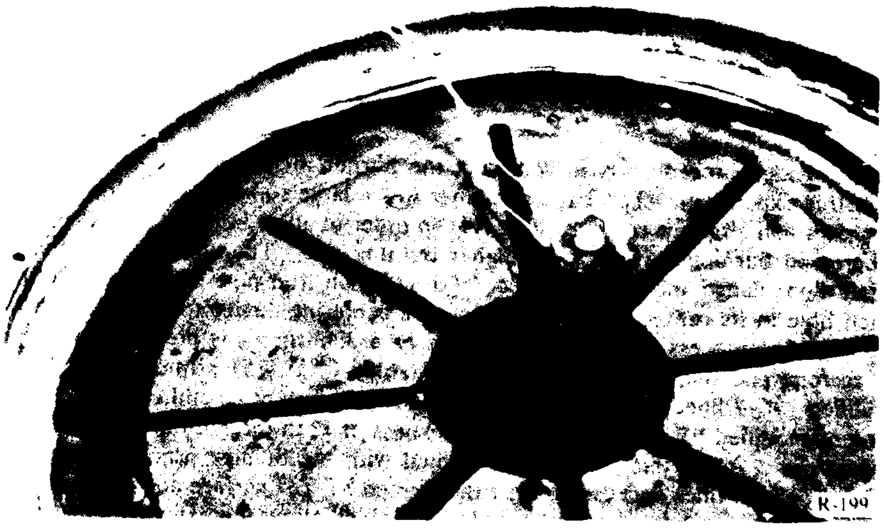


Fig. A-1 — Type 3 pyrotechnic with electric ignitor and showing radial slots

ILMED

8